

JPL PUBLICATION 77-77

(NASA-CR-155946) AN OVERVIEW OF US ENERGY
OPTIONS: SUPPLY- AND DEMAND-SIDE HISTORY
AND PROSPECTS (Jet Propulsion Lab.) 73 p
HC A04/UF A01 CSCL 102

N78-19610

Unclass
03633

G3/44

Economics and Policy Analysis Series

An Overview of U.S. Energy Options: Supply- and Demand- Side History and Prospects

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED
FROM THE BEST COPY FURNISHED US BY
THE SPONSORING AGENCY. ALTHOUGH IT
IS RECOGNIZED THAT CERTAIN PORTIONS
ARE ILLEGIBLE, IT IS BEING RELEASED
IN THE INTEREST OF MAKING AVAILABLE
AS MUCH INFORMATION AS POSSIBLE.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. JPL Pub. 77-77	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle An Overview of U.S. Energy Options: Supply- and Demand- Side History and Prospects		5. Report Date February 25, 1977	
		6. Performing Organization Code	
7. Author(s) A. S. Hirshberg		8. Performing Organization Report No.	
9. Performing Organization Name and Address JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91103		10. Work Unit No.	
		11. Contract or Grant No. NAS 7-100	
		13. Type of Report and Period Covered JPL Publication	
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, D.C. 20546		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract This report provides an overview of nonsolar energy policy options available to the United States until solar energy conversion and utilization devices can produce power at a cost competitive with that obtained from fossil fuels. The economics of the development of new fossil fuel sources and of mandatory conservation measures in energy usage are clarified in the context of the historic annual rate of increase in U.S. energy demand. An attempt is made to compare the costs and relative efficiencies of energy obtainable from various sources by correlating the many confusing measurement units in current use.			
17. Key Words (Selected by Author(s)) Engineering (General) Social Sciences (General)		18. Distribution Statement Unlimited - Unclassified	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 72	22. Price

HOW TO FILL OUT THE TECHNICAL REPORT STANDARD TITLE PAGE

Make items 1, 4, 5, 9, 12, and 13 agree with the corresponding information on the report cover. Use all capital letters for title (item 4). Leave items 2, 6, and 14 blank. Complete the remaining items as follows:

3. Recipient's Catalog No. Reserved for use by report recipients.
7. Author(s). Include corresponding information from the report cover. In addition, list the affiliation of an author if it differs from that of the performing organization.
8. Performing Organization Report No. Insert if performing organization wishes to assign this number.
10. Work Unit No. Use the agency-wide code (for example, 923-50-10-06-72), which uniquely identifies the work unit under which the work was authorized. Non-NASA performing organizations will leave this blank.
11. Insert the number of the contract or grant under which the report was prepared.
15. Supplementary Notes. Enter information not included elsewhere but useful, such as: Prepared in cooperation with... Translation of (or by)... Presented at conference of... To be published in...
16. Abstract. Include a brief (not to exceed 200 words) factual summary of the most significant information contained in the report. If possible, the abstract of a classified report should be unclassified. If the report contains a significant bibliography or literature survey, mention it here.
17. Key Words. Insert terms or short phrases selected by the author that identify the principal subjects covered in the report, and that are sufficiently specific and precise to be used for cataloging.
18. Distribution Statement. Enter one of the authorized statements used to denote releasability to the public or a limitation on dissemination for reasons other than security of defense information. Authorized statements are "Unclassified-Unlimited," "U.S. Government and Contractors only," "U.S. Government Agencies only," and "NASA and NASA Contractors only."
19. Security Classification (of report). NOTE: Reports carrying a security classification will require additional markings giving security and downgrading information as specified by the Security Requirements Checklist and the DoD Industrial Security Manual (DoD 5220.22-M).
20. Security Classification (of this page). NOTE: Because this page may be used in preparing announcements, bibliographies, and data banks, it should be unclassified if possible. If a classification is required, indicate separately the classification of the title and the abstract by following these items with either "(U)" for unclassified, or "(C)" or "(S)" as applicable for classified items.
21. No. of Pages. Insert the number of pages.
22. Price. Insert the price set by the Clearinghouse for Federal Scientific and Technical Information or the Government Printing Office, if known.

JPL PUBLICATION 77-77

Economics and Policy Analysis Series

**An Overview of U.S. Energy
Options: Supply -and Demand-
Side History and Prospects**

Alan S. Hirshberg

February 25, 1977

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Printed by the Jet Propulsion Laboratory,
California Institute of Technology as a working
paper related to Project SAGE sponsored by
the Southern California Gas Company. Any
opinions, findings, conclusions or recommendations
expressed in this publication are those of the
authors and do not necessarily reflect the views of the
Southern California Gas Company.

PREFACE

In 1974-5 while writing my Ph. D. dissertation on energy policy and solar energy, I became aware of the need to develop a comprehensive overview of energy use in the United States. Much of the literature on the subject provides only part of the picture, e. g., a summary of gasoline consumption but limited discussion of either oil supply or fuel oil use for homes in the same context. Further, the conventional wisdom concerning future energy use either did not adequately reflect opportunities for energy conservation or else it ignored conservation completely; that is, supply-side energy policy options (new fossil fuel source development) were considered apart from the potential of demand-side options (energy conservation).

This report is my attempt to come to grips with both types of energy policy options and then to provide an overview of nonsolar energy options for the United States. I will attempt to clear away some of the fog concerning energy — why energy is important, the large uncertainty surrounding energy questions, and the units of energy use (Btu, barrels of oil, kWh, etc.)

A secondary intent of this report is to generate discussion of energy policy issues with the full dimensions of supply and demand as a context. Hopefully, the report will provide comments and offer a basis for further energy policy work. This report is one in a series of reports in JPL's: "Economics and Policy Analysis Series". Since the author is no longer with the Jet Propulsion Laboratory, questions regarding this report may be directed to Dr. R. P. O'Toole, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California, 91103.

ORIGINAL PAGE IS
OF POOR QUALITY

ABSTRACT

This report provides an overview of nonsolar energy policy options available to the United States until solar energy conversion and utilization devices can produce power at a cost competitive with that obtained from fossil fuels. The economics of the development of new fossil fuel sources and of mandatory conservation measures in energy usage are clarified in the context of the historic annual rate of increase in U.S. energy demand. An attempt is made to compare the costs and relative efficiencies of energy obtainable from various sources by correlating the many confusing measurement units in current use.

CONTENTS

I.	INTRODUCTION -----	1-1
A.	WHAT IS ENERGY AND WHY IS IT IMPORTANT? -----	1-2
B.	UNCERTAINTY -----	1-9
C.	THE UNITS OF ENERGY USE -----	1-10
D.	ENERGY DEMAND: AN OVERVIEW -----	1-12
1.	Energy Use by Sector -----	1-12
2.	Fuel Use by Sector -----	1-15
3.	Significant Energy End Uses -----	1-16
4.	Energy Use Within Sectors -----	1-16
E.	TOTAL FUEL AND ENERGY USE -----	1-19
F.	FUTURE ENERGY USE AND FUEL USE -----	1-22
1.	Fuel Resource Flows and Use -----	1-23
G.	DEMAND-SIDE ENERGY SAVING OPTIONS: AN OVERVIEW -----	1-29
1.	New or Improved Technology and Improved Efficiency -----	1-29
2.	Organizational Arrangements -----	1-33
3.	Consumer Behavior Changes -----	1-37
4.	Summary -----	1-39
H.	SUPPLY-SIDE ENERGY OPTIONS: AN OVERVIEW -----	1-47
1.	Minerals -----	1-47
2.	Summary -----	1-55
	REFERENCES -----	2-1

Figures

1-1.	Energy Use and Gross National Product - - - - -	1-5
1-2.	Energy and Oil Consumption Per Capita - - - - -	1-6
1-3.	Commercial Energy Use and Gross National Product - - - - -	1-7
1-4.	End Uses of Energy, United States, 1968 - - - - -	1-14
1-5.	Residential Energy Consumption - 1971 Sources of Supply, Actual and Projected - - - - -	1-18
1-6.	U.S. Fuel Sources, 1850 to 1970 - - - - -	1-20
1-7.	Sources of U.S. Energy Supply 1920, 1950, 1973 - - - - -	1-21
1-8.	Sources and Uses of U.S. Oil in 1973 - - - - -	1-25
1-9.	Transportation Energy Consumption of Various Modes - - - - -	1-36
1-10.	Annual U.S. Primary Energy Demand and Domestic Supply - Two Projections - - - - -	1-44
1-11.	Annual U.S. Primary Energy Imports and Total Number of Tankers Required (250,000 DWT) - Three Projections - - - - -	1-45
1-12.	Classification of Mineral Resources - - - - -	1-49
1-13.	Total Solar Radiation Flow - - - - -	1-54
1-14.	Depletion of Domestic Crude Oil Reserves - - - - -	1-56
1-15.	Depletion of World Crude Oil Reserves - - - - -	1-57
1-16.	Cost of United States Crude Oil at the Well, 1935 to 1941 - - - - -	1-58
1-17.	Crude Oil Cost Projected Toward Depletion for a Total Resource Base of 17,250 Q - - - - -	1-60
1-18.	Planning Schedule for a Light-Water Reactor Plant - - - - -	1-61
1-19.	Fuel Price Comparison for Different Efficiencies and for Solar Energy - - - - -	1-62

ORIGINAL PAGE IS
OF POOR QUALITY

Tables

1-1.	Total Horsepower of All Prime Movers 1940-68 - - - - -	1-3
1-2.	Energy Efficiency for Passenger Transport - - - - -	1-8
1-3.	Energy Efficiency for Freight Transport - - - - -	1-8
1-4.	Energy Unit Conversion Between Fuels and in Btus - - - - -	1-11
1-5.	United States Energy Uses: 1960, 1968, 1973 - - - - -	1-13
1-6.	Energy Use for Heating and Cooling Buildings in 1968 (% of total energy consumed in the United States) - - - - -	1-13
1-7.	Energy Use by Sector in 1968 - - - - -	1-15
1-8.	Significant End Uses in 1968 - - - - -	1-17
1-9.	Sources of Energy for the United States in 1970 - - - - -	1-22
1-10.	Comparison of Energy Growth Scenarios - - - - -	1-24
1-11.	Major Demands for Petroleum Products in 1973 - - - - -	1-27
1-12.	Major Demands for Natural Gas in 1973 - - - - -	1-28
1-13.	Major Demands for Coal in 1973 - - - - -	1-28
1-14.	Electric Power Consumption and Sources of Supply for 1968 and 1973 - - - - -	1-30
1-15.	1973 Fossil Fuel Use by Electric Utilities - - - - -	1-31
1-16.	Maximum Efficiency of Selected Energy Converters End Use Sector - - - - -	1-32
1-17.	Energy Savings Potential by Sector - - - - -	1-34
1-18.	Energy Savings by Type for all Sectors - - - - -	1-35
1-19.	Energy Savings by Demand Reduction by Sector - - - - -	1-40
1-20.	Historical Growth Scenario of Energy Use - - - - -	1-42
1-21.	Estimates of U.S. Reserves - - - - -	1-50
1-22.	United States Fossil Fuel Reserves and Resources - - - - -	1-50
1-23.	Total United States Reserves and Resources - - - - -	1-51
1-24.	Cost Comparison of Different Fuels and Solar Energy - - - - -	1-52

SECTION I
INTRODUCTION

Time present and time past
are both perhaps present in time
future, and time future contained
in time past.

T. S. Eliot
Burnt Norton

The United States with less than 6% of the world's population consumes over one-third of the world's annual energy output (Reference 1-1). About 75% of U.S. energy comes from natural gas and oil. The producing, refining, distributing and using of this energy accounts directly for \$125 billion annually or 10% of the GNP (Reference 1-2). Clearly, energy is an ubiquitous part of our national life and the energy dilemma and crisis have important ramifications for society.

This report will explore the question of energy production and use in the United States in order to provide a context for understanding the role of solar energy, energy conservation and other options in the solution of the dilemma. A supply/demand approach will be used to provide a framework for understanding this Report. First, the demand for energy in the United States will be discussed. The amount of energy used in each major energy consuming sector and the amount of different fuels (oil, etc.) used by these sectors will be explored. Second, the energy supply situation will be studied. This will encompass both the supply of conventional mineral resources (e. g., oil), as well as an overview of new supply technologies (e. g., nuclear power). Third, a comparison of the supply and demand energy trends will be made, both to define the energy problem quantitatively and to help understand which solutions can make a difference. Before discussing these three items, however, it will be helpful to discuss why energy is important, the energy supply uncertainty which is one characteristic of the energy dilemma, and the basic units of energy use.

A. WHAT IS ENERGY AND WHY IS IT IMPORTANT?

Energy is the ability to do work. Power is the rate of doing work.

For centuries the only sources of energy were the muscles of man and beast, supplemented slightly by energy that could be tapped from moving winds and water. With the invention of the steam engine and the coming of the industrial revolution, modern man began to use large amounts of energy derived from burning fuels, and the power output of his machines increased. A full-grown man is capable of an average power output of about 1/20th of a horsepower during an 8-hour working day, equivalent to an output of about 37 watts of electrical energy. Thus, when a child turns on a 150-watt television receiver, he commands electrical energy equivalent to the energy output of four grown men. As long as human progress depended mostly on the energy of human muscles, there could not be much physical change in the conditions of primitive life.

Today human labor provides energy for far less than 1 percent of the work performed in factories, refineries, and mills in the production of their products. Literally, our economy and our way of life could not continue without use of vast amounts of energy.

One measure of this situation is the increase in the total power for all engines, turbines, and work animals over the past 3 decades. Table 1-1 shows the increase from 2.7 billion horsepower available in the United States in 1940 to 17.9 billion for 1968. Of this, engines in trucks, buses, and automobiles accounted for by far the largest part increasing from 2.5 billion horsepower in 1940 to 16.9 billion horsepower in 1968. Over the same period, the power of electric generating stations increased from 53 million horsepower to 371 million horsepower (U.S. Joint Economic Committee, 1971, pp. 1-3).

The significance of the rapid increase in power between 1940 and 1968 has widespread ramifications: social, political, and economic. The replacement of human labor by machine power has been one of the most significant social forces in our society as observed by many writers (References 1-3 and 1-4). The ability to cybernate the historical functions of man using machine power is a mixed blessing: it frees us to pursue self-actualizing experiences but also robs us of the traditional modes of self-identity, of feeling good about ourselves, and has lead to at least some degree of alienation (Reference 1-5).

Table 1-1. Total Horsepower of all Prime Movers 1940-68

(In thousands. As of January, except as noted. Prior to 1960, excludes Alaska and Hawaii, except as noted. Prime movers are mechanical engines and turbines, and work animals, which originally convert fuels or force (as wind or falling water) into work and power. Electric motors, which obtain their power from prime movers, are excluded to avoid duplication. See also Historical Statistics Colonial Times to 1957, series S1-14).

Item	1940	1950	1955	1960	1965	1968 (preliminary)
Total horsepower	2, 773, 316	4, 867, 538	7, 158, 229	11, 007, 889	15, 096, 332	17, 912, 944
Work animals	12, 510	7, 040	4, 141	2, 790	2, 000	1, 460
Inanimate	2, 760, 806	4, 860, 498	7, 154, 088	11, 005, 099	15, 094, 332	17, 910, 684
Automotive ^{a, b}	2, 511, 312	4, 403, 617	6, 632, 121	10, 366, 880	14, 306, 300	16, 937, 725
Nonautomotive	249, 494	456, 881	521, 967	638, 219	788, 032	972, 959
Factories	21, 768	32, 921	35, 579	42, 000	48, 400	52, 000
Mines	7, 332	22, 000	30, 768	34, 700	40, 300	43, 400
Railroads ^c	92, 361	110, 969	60, 304	46, 856	43, 838	57, 607
Merchant ships, powered	^d 9, 408	^d 23, 423	^d 24, 155	23, 890	24, 015	20, 413
Sailing vessels	^d 26	^d 11	^d 5	2	2	1
Farms	57, 472	157, 533	207, 742	237, 020	269, 822	290, 600
Windmills	130	59	59	44	30	24
Electrical central stations ^b	53, 542	87, 965	137, 576	217, 173	307, 025	371, 756
Aircraft ^{c, e}	^d 7, 455	^d 22, 000	⁴ 25, 779	36, 534	54, 600	137, 158

^aIncludes passenger cars, trucks, buses, and motorcycles.

^bAs of July 1.

^cBeginning 1965, not strictly comparable with earlier years.

^dIncludes Alaska and Hawaii.

^eIncludes private planes and commercial airlines.

The growth of machine power and our reliance on foreign sources for the fuel energy to run them has produced political pressures. There are pressures to keep fuel prices low because of the necessity (real or perceived) to continue using these machines. Society, if it has been freed by the machine, is also enslaved by it. People living in dispersed communities, whose work is a long distance away, have little choice but to use transportation to get to work. Any increase in the cost of the transportation generally meets strong political resistance. The political problems are heightened by the fact that in 1973 about one-third of our oil came from foreign sources which were not directly under U.S. control.

The growth of machine power and technology has also meant a growth in U.S. wealth (mean income per capita). During the period 1940 to 1970 total energy demand increased at an average annual rate of 3.7% per year. During the same period, real GNP increased 3.9% per year. Per capita GNP increased at 2.4% per year while population was increasing at only 1.5% per year (Reference 1-6). Figure 1-1 shows the growth of both energy use and GNP in the United States from 1920 to 1985. (The numbers after 1970 are estimates). Figure 1-2 shows both the per capita energy and oil use in the U.S. in 1970 compared to other countries. The correlation between energy consumption and wealth is shown in Figure 1-3. The U.S., with the highest per capita GNP has the highest commercial per capita energy consumption. Although there is evidence that the relationship between GNP and energy consumption need not be as direct and functional as suggested by the figure (Ford Energy Policy Project), the historical relationship is dramatic and clear.

Evidently, our social and economic choices of more energy use have resulted in a great reliance upon energy fuels. One of the most persuasive indicators of this reliance is the change to more energy intensive modes for the same type of work. Nowhere is this more evident than in transportation. An automobile trip to the market and back requires 27 times more energy per passenger mile than walking. For intercity travel, airplanes require 2.5 times more energy per passenger mile than driving. Similarly, a ton of freight shipped by truck requires about 5.5 times more energy than shipping that same ton by rail. The energy efficiency of passenger and freight transport are summarized in Tables 1-2 and 1-3.

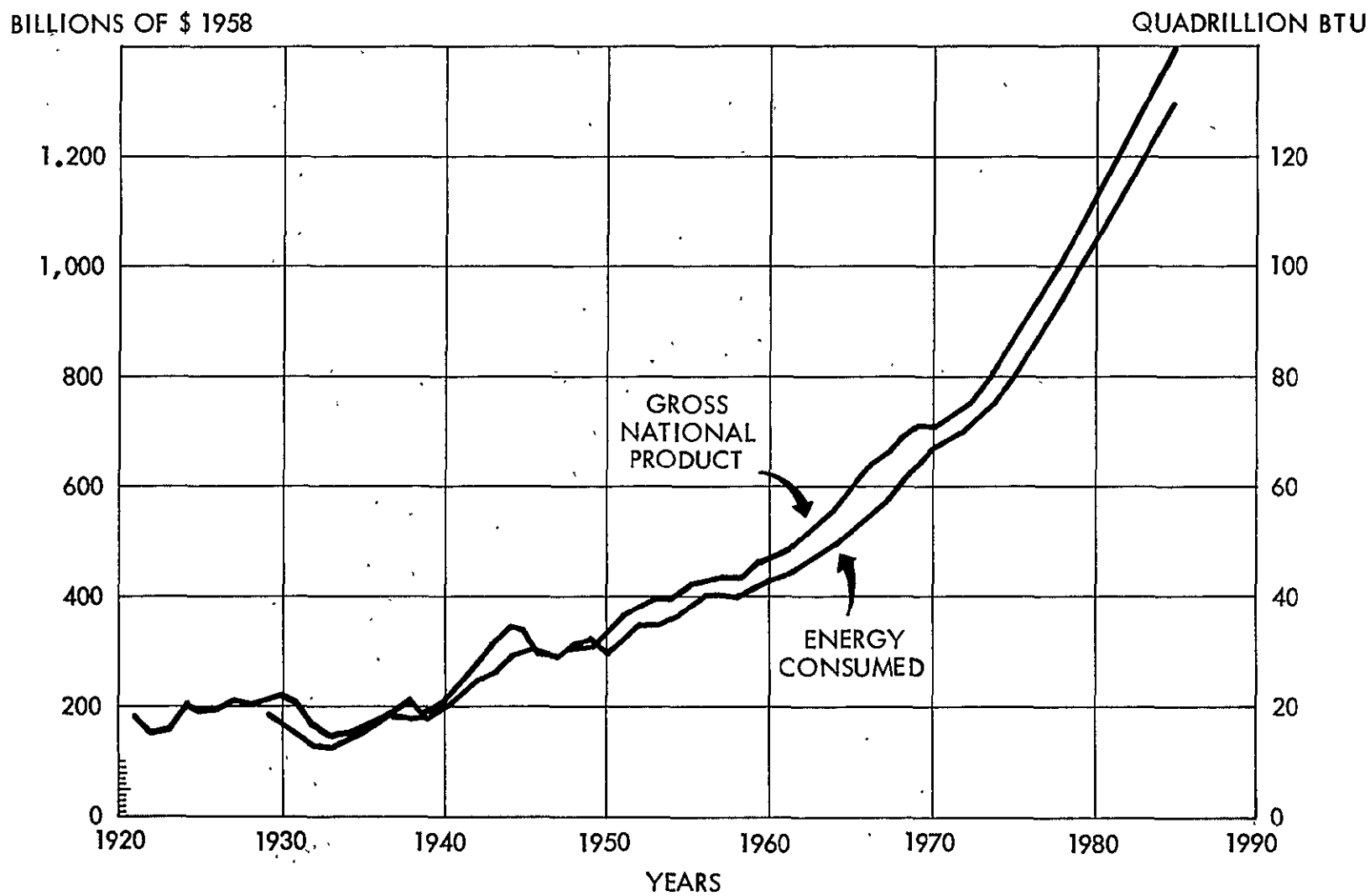
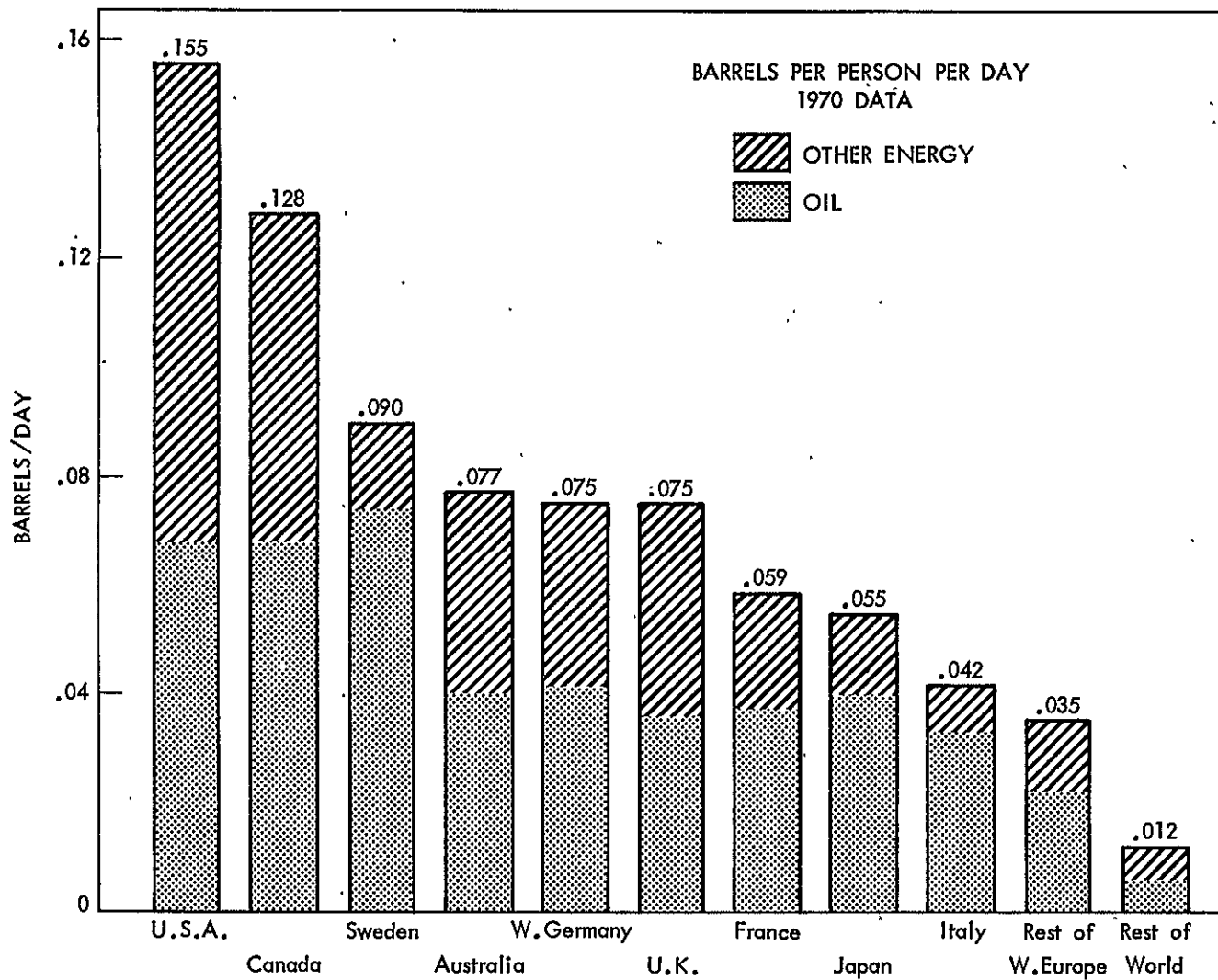


Figure 1-1. Energy Use and Gross National Product

ORIGINAL PAGE IS
OF POOR QUALITY



Source: U.S. Treasury

Figure 1-2. Energy and Oil Consumption Per Capita

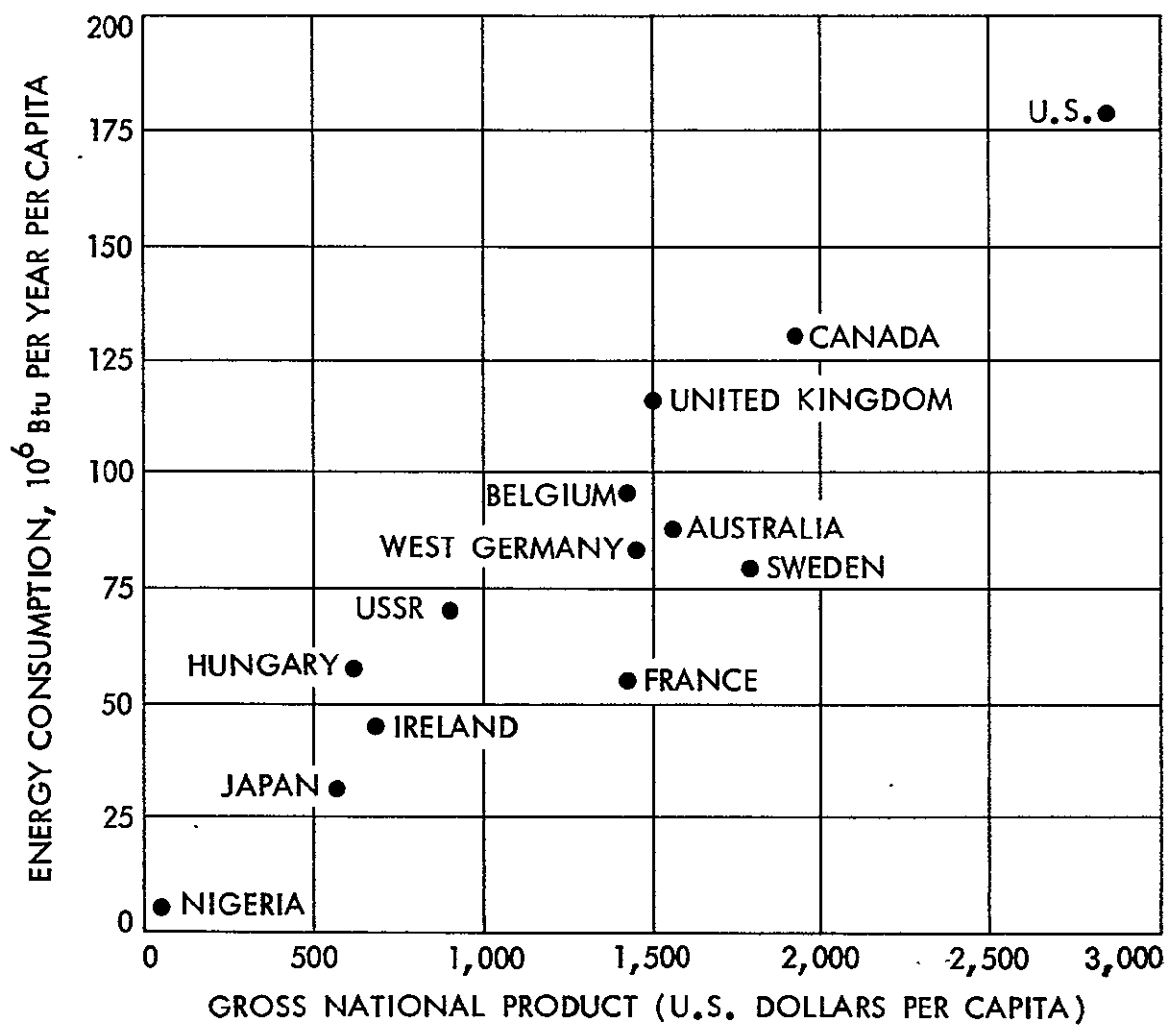


Figure 1-3. Commercial Energy Use and Gross National Product

Table 1-2. Energy Efficiency for Passenger Transport

Item	Btu Per Passenger Mile	
	Urban	Intercity
Bicycle	200	
Walking	300	
Buses	3700	1600
Railroads		2900
Automobiles	8100	3400
Airplanes		8400

Source: E. Hirst, Oak Ridge National Laboratory.

Table 1-3. Energy Efficiency for Freight Transport

Item	Btu Per Ton Mile
Pipeline	450
Railroad	670
Waterway	680
Truck	3,800
Airplane	42,000

Source: E. Hirst, Oak Ridge National Laboratory.

ORIGINAL PAGE IS
OF POOR QUALITY.

B. UNCERTAINTY

Another key characteristic of the energy crisis is the uncertainty surrounding the answers to basic energy questions. Uncertainty pervades the energy crisis, not only in terms of the reliability of foreign energy but also in terms of projections of: 1) domestic resource supplies, 2) future energy demand, and 3) the cost and availability of new energy technology, etc. The uncertainty of the projections of future demand lead to a Congressional committee comment about the "strikingly different estimates" of future energy demand ("Considerations in the Formulation of National Energy Policy" by D. Beard prepared for the Committee on Interior and Insular Affairs, United States Senate, September 1971, p. 31). The uncertainty is a result, in part, of the lack of federal government involvement in energy matters prior to the Oil Embargo of 1973. The U.S. energy policy was characterized proudly by an official U.S. spokesman to the Energy Committee of the OECD as a "de facto" or "hands-off" policy. Total reliance was placed upon the private sector with no coordinated attempt by the federal government to formulate a national energy policy (Reference 1-7).

Prior to the formation of Energy Research and Development Administration (ERDA) in 1975, no less than 13 Senate and 13 House committees had control over some important phase of U.S. energy delivery mechanism. The dispersal of responsibility is "even more prominent in the Executive Branch, where there are some 85 bureau-level organizations that have substantial concern with one or another aspect of the energy field" (Reference 1-7, p. 87). The lack of a rational, long range energy policy not only increases the uncertainty surrounding the energy dilemma, but also is a major social failure (Reference 1-2, p. 63).

Uncertainty was not produced exclusively by the lack of a national energy policy. It was also caused by the complexity of energy use in the U.S. and the variety of projections which "emanate from many sources and are of different quality, drawn to different specifications, with different coverage; and not infrequently (which) are designed to promote some particular interest" (Reference 1-8, p. 130). One method for reducing this uncertainty is to develop a set of scenarios rather than rely on single projections. The scenarios can be

used to bound the likely cases which may occur in the future and to represent very different future consumer energy consumption behavior. For example, the Ford Foundation Energy Policy Project used scenarios to study three energy futures: continued historical growth of energy consumption, modified growth using appropriate technology for conservation or supply substitution, and zero energy growth. Although scenarios, or at least ranges of estimates for energy would be desirable, only a best-guess estimate will be presented for this study. These estimates will help set the context for understanding the potential role of solar energy in the energy dilemma. Before presenting these estimates, the units of energy consumption will be given.

C. THE UNITS OF ENERGY USE

For the purpose of this study the basic units of energy use will be the British Thermal Unit (Btu). A Btu is the amount of energy required to raise 1 lb of water 1°F. In 1968 total U.S. energy consumption was 60.5 quadrillion Btu. One quadrillion Btu (1 quad) is approximately the amount of energy used for water heating in all U.S. residences in 1960. (Because of the magnitude of energy consumption, most figures will be given in terms of quadrillion Btu or quads). For comparison, the average household uses 400 million Btu per year or about four one-millionths of a quad.

There are four basic fuels in our economy — natural gas, crude oil, coal, and electricity. (Electricity is considered to be a "fuel" although it is produced from the other three fuels). The basic unit of natural gas is the cubic foot (CF). A CF of natural gas produces about 1000 Btus. It follows that 1000 CF of natural gas (abbreviated MCF) produces 1 million Btu (MBtu). The basic unit of crude oil is a barrel (bbl). One barrel of oil contains approximately 5.6 million Btu (MBtu). Because of the prevalence and political importance of oil, energy consumption is often quoted in barrel of oil equivalents (bble). For example, 1 quad is equivalent to 180 million bbl of oil. Bituminous coal has the basic units of tons (T). A ton of coal provides between 22 and 26 million Btu depending on the quality of the coal. The basic unit of electricity is the kilowatt hour (kWh). One quad (a quadrillion Btu) is equivalent to 1 trillion CF of natural gas (TCF), 180 million barrels of crude oil, 40 million tons (MT) of coal, and 293 million kWh of electricity. The conversion between fuels and in Btus is given in Table 1-4.

Table 1-4. Energy Unit Conversion Between Fuels and in Btus

ENERGY UNIT CONVERSION CHART^a

Cubic Feet Natural Gas ^b (CF)	Barrels Oil (bbl)	Short Tons Bituminous Coal (T)	British Thermal Units (Btu)	Kilowatt Hours Electricity (kWh)
-	-	-	1	0.000293
1	0.00018	0.00004	1000	0.293
3.41	0.00061	0.00014	3413	1
1000 (1 MCF)	0.18	0.04	1 Million	293
3413	0.61	0.14	3.41 Million	1000 (1 MWh)
5600	1	0.22	5.6 Million	1640
25,000	4.46	1	25 Million	7325
1 Million (1 MMCF)	180	40	1 Billion	293,000
3.41 Million	610	140	3.41 Billion	1 Million (1 GWh)
1 Billion (1 BCF)	180,000	48,000	1 Trillion	293 Million
1 Trillion (1 TCF)	180 Million	40* Million	1 Quadrillion (Quad) (Q)	293 Billion

^aBased on the following fuel heating values:

1 Cubic Foot Natural Gas - 1000 Btu

1 Barrel Crude Oil - 5.6 million Btu

1 Pound Bituminous Coal - 12,500 Btu

^bSubstitute Natural Gas (SNG) and Liquefied Natural Gas (LNG) will have approximately the same heating value.

ORIGINAL PAGE IS
OF POOR QUALITY

1-11

77-77

D. ENERGY DEMAND: AN OVERVIEW

1. Energy Use by Sector

In order to understand the role of solar energy in solving the U.S. energy problem, it is important to take a look at the sectors in which energy is used. The four primary ones are: residential, commercial, industrial, and transportation. The residential sector as of 1973 used about 21.7% of all energy consumed in the country; the commercial sector approximately 13.9%; the industrial sector about 39.3%; and transportation, including trucking, rail, and air transport consumed about 25.1%. The total energy use in the country in 1973 was 75.0 quads, up from 43.1 quads in 1960. This is a compounded annual growth rate of 4.4%.

Among the four major sectors in terms of use of energy, the one that displayed the largest energy growth between 1960 and 1973 was the commercial sector which grew at an average rate of 5.4%. Right behind that was the residential sector increasing 4.8%, followed by the transportation sector at 4.1%, and then industrial at 3.9%. Table 1-5 summarizes this information for 1960, 1968, and 1973.

Details of the energy end uses within each of these sectors are instructive. Within the industrial sector six industries consume over two-thirds of the energy used by all of industry. The industries are: primary metals; chemicals and allied products; petroleum refining; food processing; paper; stone, glass, and clay. Together they used 17 quads or 28% of the total U.S. energy demand in 1973.

The largest energy end use in the transportation sector are private automobiles. They consumed 13% of all the primary energy demand. Trucks used less than one-third as much as autos, and airplanes consumed only 2% of the total energy supply.

Space heating is the dominant energy use in both residential and commercial sectors, followed by water heating as the second greatest use in the residential sector, and space cooling (air conditioning) in the commercial

sector. Table 1-6 depicts the energy consumption in the commercial and residential sectors. Figure 1-4 summarizes the percentage energy consumption in each of the sectors and the split of end use within each sector for 1968.

Table 1-5. United States Energy Uses: 1960, 1968, 1973

	<u>1960^b</u>	<u>1968^b</u>	<u>1973^a</u>	<u>Average Growth Rate</u>
	%	%	%	%
Residential	18.6	17.2	21.7	4.8
Commercial	13.2	14.4	13.9	5.4
Industrial	42.7	41.2	39.3	3.9
Transportation	25.5	25.2	25.1	4.1
Total Btu x 10 ¹⁵	43.1	60.5	75.0	4.2

Source: ^aFord Foundation Energy Policy Project, 1974.

^b"Pattern of Energy Consumption in the United States," Stanford Research Institute Report, January 1972.

Table 1-6. Energy Use for Heating and Cooling Buildings in 1968
(% of total energy consumed in the United States)

	<u>Residential</u>		<u>Commercial</u>		<u>Total</u>	
	%	Growth Rate %	%	Growth Rate %	%	Growth Rate %
Space Heating	11.0	4.1	6.9	3.8	17.5	4.0
Water Heating	2.9	5.2	1.1	2.3	4.0	3.1
Space Cooling	0.7	15.6	1.8	8.6	2.5	8.8
Total	14.6		9.8		24.4	

Source: "Pattern of Energy Consumption in the United States,"
Stanford Research Institute Report, January 1972.

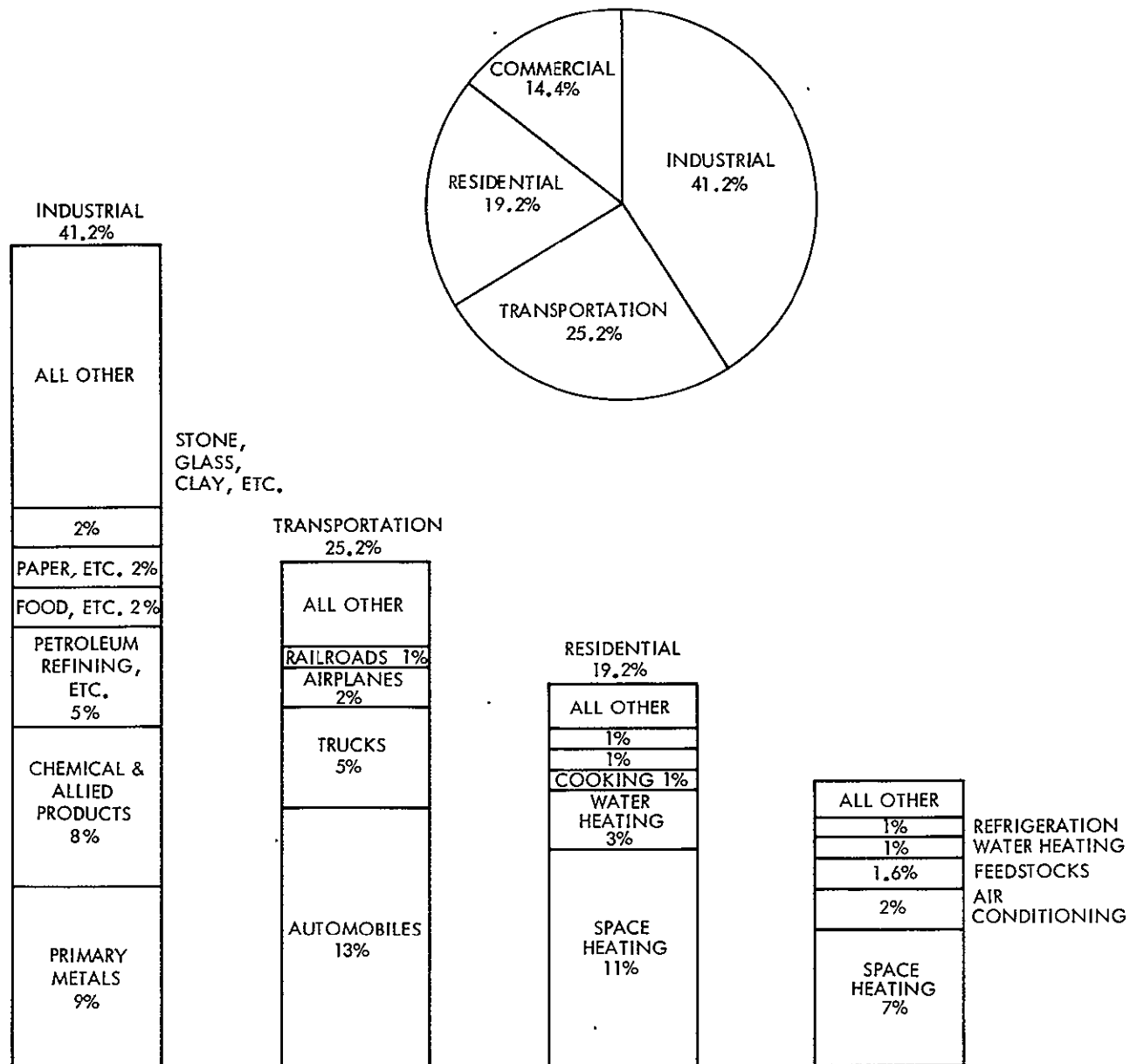


Figure 1-4. End Uses of Energy, United States, 1968

2. Fuel Use by Sector

The relative importance of the four primary fuels in each sector is given in Table 1-7. In 1968 the main fuel for residential end uses was natural gas which supplied slightly over 50% of the residential energy requirements. Despite the ubiquitous nature of home electrical appliances, their total addition to the residential energy requirement is quite small. Total electricity used in the residential sector accounted for only 15% of residential energy use. Coal use is restricted primarily to the industrial sector, yet supplies only 26% of the total industrial energy needs. Surprisingly, natural gas accounts for the largest share of the energy used by industry, supplying 43% of industrial energy. As expected, 95% of the energy used for transportation comes from petroleum.

Table 1-7. Energy Use by Sector in 1968

<u>Percentage of Sector Requirements - 1968</u>					
	<u>Coal</u>	<u>Gas</u>	<u>Petroleum</u>	<u>Electricity</u>	<u>Total</u>
Residential	-%	50.1%	34.8%	15.1%	100.0%
Commercial	8.3	26.8	49.2	15.7	100.0
Industrial	26.2	43.3	20.9	9.6	100.0
Transportation	0.1	4.0	95.8	0.1	100.0

The contribution of each fuel to the requirements of the utility sector in 1968 was:

Coal	57.3%
Gas	26.1
Petroleum	9.5
Hydro and nuclear	<u>7.1</u>
	100.0%

Source: Stanford Research Institute, 1972.

ORIGINAL PAGE IS
OF POOR QUALITY

3. Significant Energy End Uses

Twelve end uses account for all but 3% of the nation's total energy consumption in 1968, as shown in Table 1-8. The remaining 3% is consumed by various electric appliances including television, which uses 0.7% of total primary energy. The top four end uses (transportation, space heating, industrial process heat, and direct heat) account for about 75% of all energy consumption. Because of the stability of energy use, we can expect that the nearly same fractional distribution by use will remain the same. The rapidly growing uses, such as space cooling, are much smaller in magnitude and the shifts in end use consumption will take place only gradually (Reference 1-9, p. 7).

4. Energy Use Within Sectors

Another interesting feature of energy consumption is to look at the types and forms of energy used by each of the sectors. The residential sector consumed primarily natural gas, and secondly electricity. Petroleum use in the residential sector began to decline after 1965 and coal, for residential use, which has been steadily declining, is projected to drop to zero before 1980. This can be seen in Figure 1-5. Looking at the energy use patterns in a different way, it is evident that combining residential and commercial uses and looking at space heating, water heating, and air conditioning, in 1968 space heating accounted for 11% of all energy used in the country for residential buildings and 6.9% for commercial buildings. Water heating accounted for 2.9% in the residential sector and 2.3% in the commercial sector. Air conditioning or space cooling accounted for only 0.7% in the residential market but 1.8% in the commercial market.

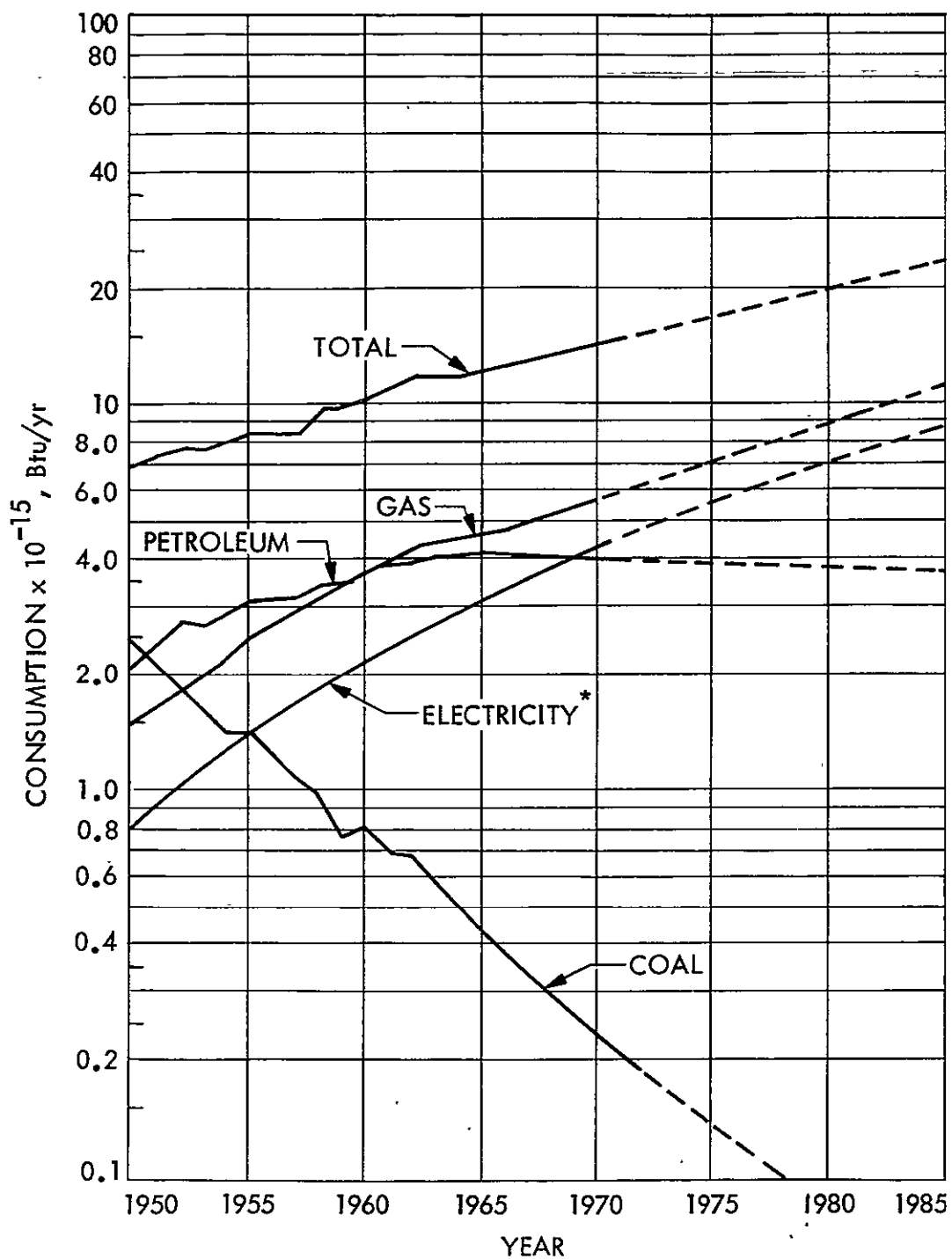
The growth rates for space heating, water heating and cooling as well as the fraction of total use that they represent for residential and commercial uses are shown in Tables 1-5 and 1-6. Table 1-6 indicates that the largest growing sector for heating and cooling of buildings is for space cooling which is growing at about 8.8% per year. Surprisingly next to that is the growth in water heating which accounts for a growth rate of 5.1%, and space heating 4%.

Table 1-8. Significant End Uses in 1968

	Percent of Total
Transportation (fuel; excludes lubes and greases)	24.9%
Space heating (residential, commercial)	17.9
Process steam (industrial)	16.7
Direct heat (industrial)	11.5
Electric drive (industrial)	7.9
Feedstocks, raw materials (commercial, industrial, transportation)	5.5
Water heating (residential, commercial)	4.0
Air conditioning (residential, commercial)	2.5
Refrigeration (residential, commercial)	2.2
Lighting (residential, commercial)	1.5
Cooking (residential, commercial)	1.3
Electrolytic processes (industrial)	1.2
Total	97.1%

Source: Stanford Research Institute, 1972.

ORIGINAL PAGE IS
OF POOR QUALITY



* $10,340 \text{ Btu/kWh}_e$

Source: Szego Report, 1971

Figure 1-5. Residential Energy Consumption — Sources of Supply, Actual and Projected

Summing the commercial and residential uses together, we find that about 17.9% of the total primary energy used in this country is to heat buildings, 4.0% is for water heating in buildings, and 2.5% is for cooling. All of these account for 24.4% of the primary energy use in the country. Thus, of the 31.6% of the total primary energy used in the residential and commercial sectors combined, 24.4% or over three-quarters of it goes for heating and cooling and water heating of buildings.

If solar energy can be applied successfully to supply much of the energy used in buildings, substantial savings can accrue and solar energy can play a very valuable role in the energy dilemma. Because the energy dilemma is both a function of total energy use and of the growth rates due to the mismatch in supply and demand, the total percentage uses are important, as are the growth rates for each of the particular energy uses in buildings. In this regard, water heating stands out. Although only 4% of the energy is used, it is growing at 5.1% per year, and is ideally suited for the application of solar energy. Of course, space heating is also important since it provides almost 18% of the energy used in buildings and contributes a 4% annual growth rate. Solar space cooling can play an important part in slowing the growth rate of energy demand; although it is only 2.5% of the total primary energy used, it is growing at 8.8% per year.

E. TOTAL FUEL AND ENERGY USE

Historically energy use has changed dramatically during the last century. In 1850 nearly two-thirds of the energy used in the United States came from wood; coal supplied only 7%, while petroleum and natural gas were not consumed at all. Between 1850 and 1910 coal slowly replaced fuel wood as the primary energy source. As the popularity of the automobile increased, coal was largely replaced by petroleum fuels. This substitution is shown in Figure 1-6 (Reference 1-10, pp. 13-15). Beginning in 1920, petroleum and natural gas grew from supplying 14 and 4% (respectively) to 46 and 31% in 1973. This dramatic growth is depicted in Figure 1-7. The total 1970 consumption of these fuels in terms of quads is given in Table 1-9.

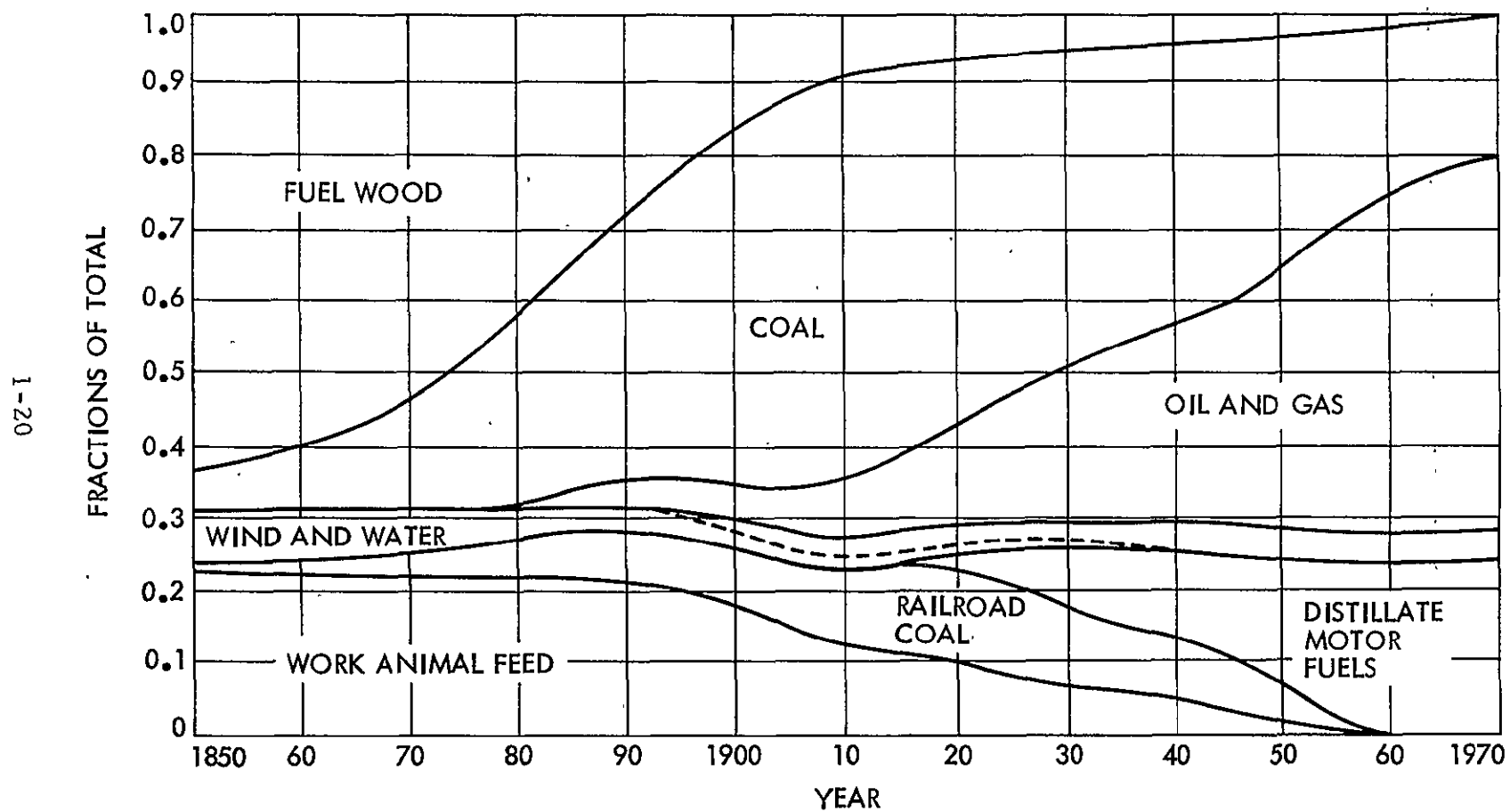


Figure 1-6. U.S. Fuel Sources, 1850 to 1970

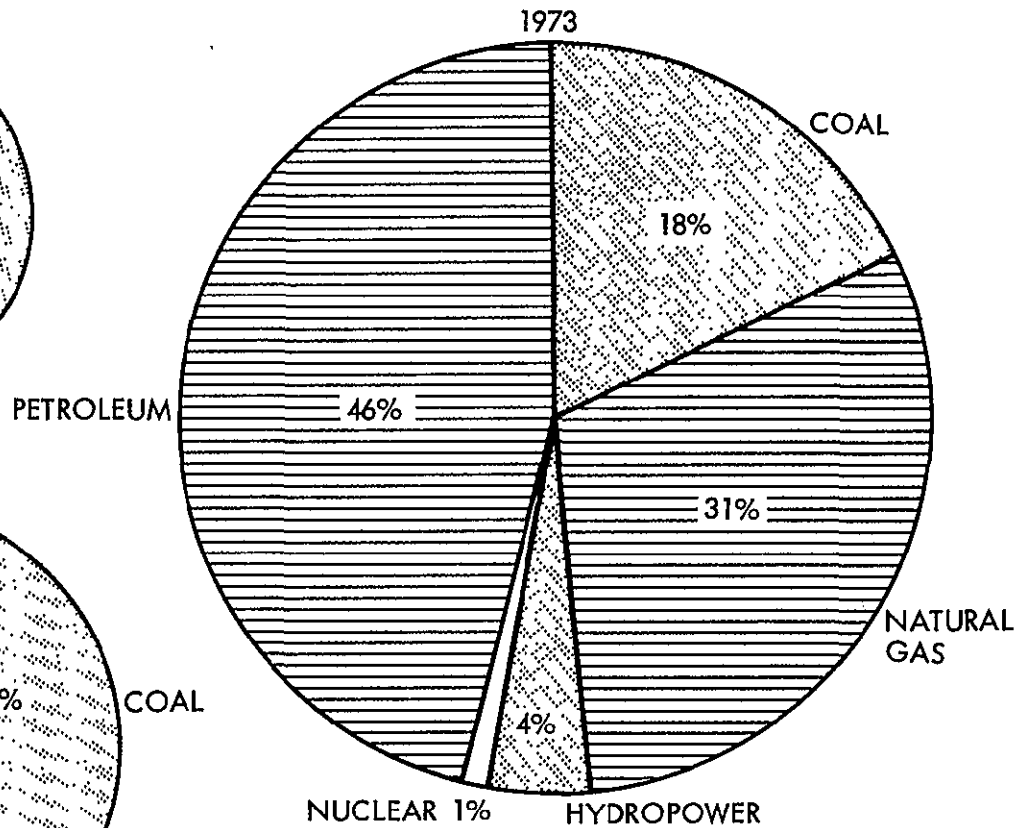
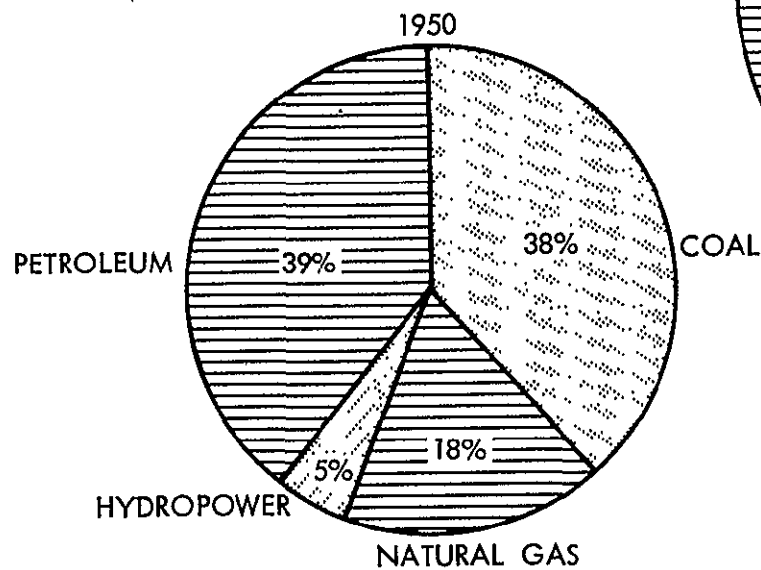
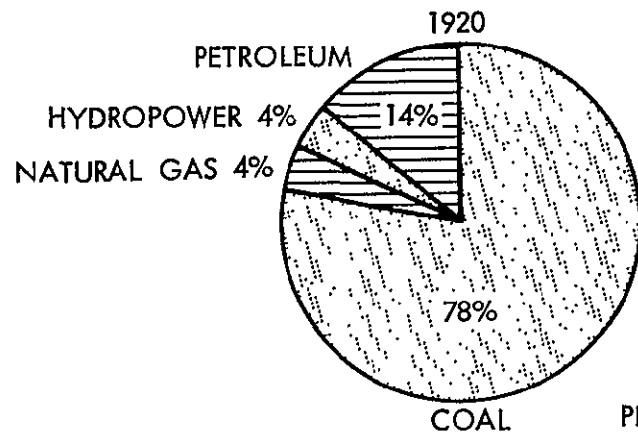


Figure 1-7. Sources of U.S. Energy Supply 1920, 1950, 1973

Table 1-9. Sources of Energy for the United States in 1970

Source	Conventional Quantity		Energy, quads
Fossil fuel			
Coal	525	million tons	12.8
Petroleum	5.36	billion barrels	26.5
Natural gas	21.4	trillion cubic feet	21.3
Solar energy			
Hydroelectricity	253	billion kilowatt-hours	2.6
Other			
Miscellaneous			<u>1.3</u>
			64.5

Source: Fisher, 1974.

F. FUTURE ENERGY AND FUEL USES

Predicting future energy consumption can be quite hazardous and depends upon many uncertain factors such as price, availability, and government policy. The Ford Energy Policy Project for its study on the energy problem developed three scenarios and made energy projections based on each of these scenarios in order "to help test and compare the consequences of different policy choices" (Reference 1-10, p. 12).

The historical growth scenario assumes a continuation of the historical growth rate to the end of the century. A vigorous drive will be made to enlarge and create new energy sources. By the year 2000, annual energy consumption will rise 150% to 18 quads. The historical scenario follows the logic of our historical approach to energy — leave demand unfettered, keep prices low, develop supply to meet the demand.

The second scenario, technical fix, reflects a conscious national effort to reduce energy consumption through engineering and practical energy saving devices. The GNP growth rate is slightly lower than for historical growth, and the energy growth rate is reduced to 1.9% annually or about half the historical

growth rate. This produces energy consumption in the year 2000 to 124 quads or a one-third reduction compared to the historical growth rate scenario. Jobs and life-styles would be maintained at nearly the same level in the technical fix case.

The zero energy growth scenario also preserves nearly the same level of economic growth and life-style choices as the historical growth scenario; however, it does produce a shift away from energy-intensive industries and toward labor-intensive ones. The zero energy growth scenario assumes a declining primary energy growth rate reaching zero before 1990. Annual energy use will reach 100 quads and remain at that level. This represents a 20% reduction from the technical fix energy consumption level and a 47% decline from the historical growth scenario by the year 2000.

A comparison of these three energy scenarios is given in Table 1-10. Each scenario shows a gradual shift in consumption away from the residential and transportation sectors to the industrial and commercial sectors. The major difference between the scenarios, in addition to total consumption, is the higher reliance upon electricity (principally from nuclear power plants) and a higher percentage of energy being devoted to transportation in the historical growth scenario.

1. Fuel Resource Flows and Use

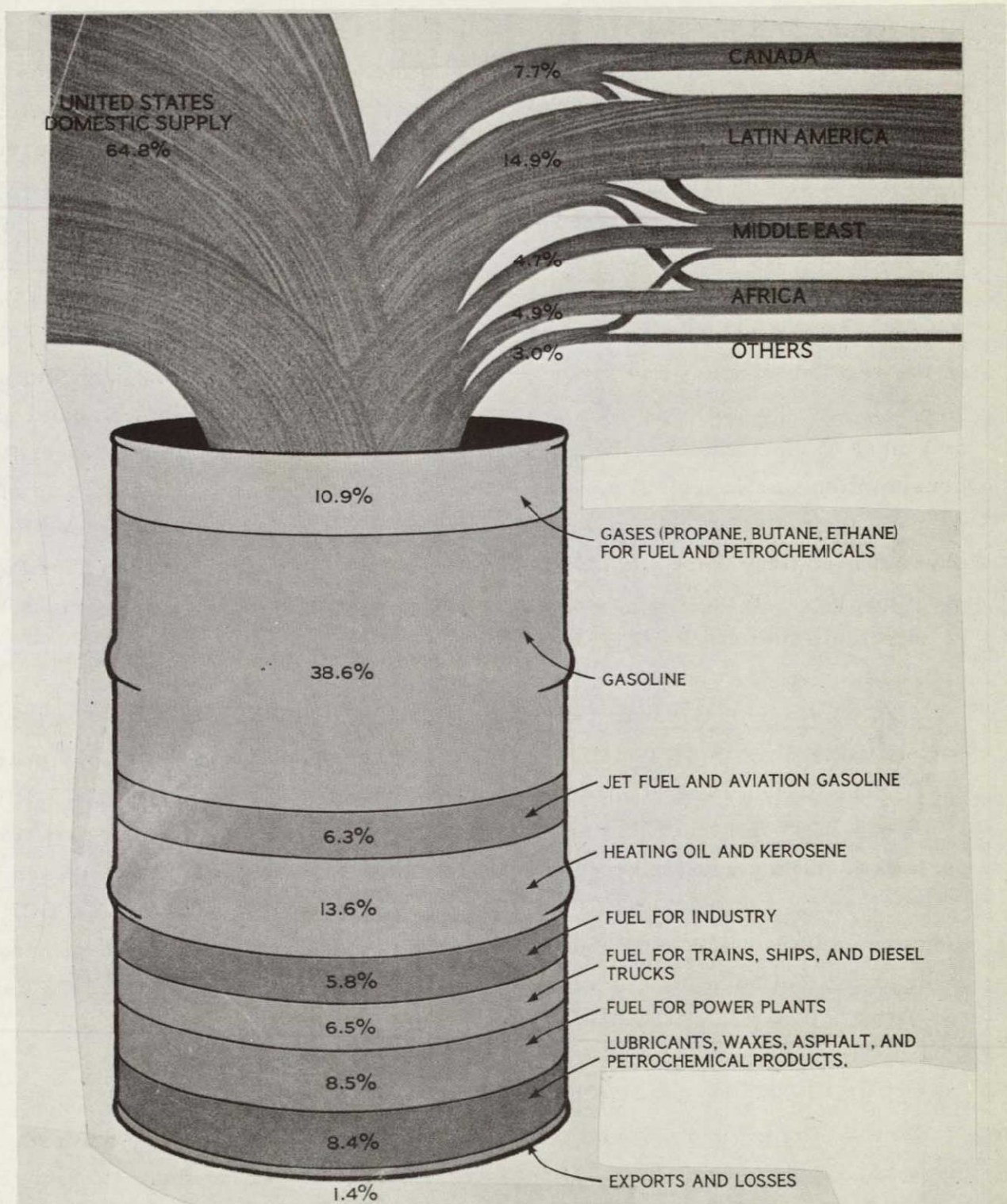
One of the interesting questions is "where does each of the major fuels come from and how is it used?" We shall examine this question fuel-by-fuel and then aggregate all fuels together.

a. Oil. Crude oil is the mainstay of the U.S. energy economy accounting for 46% of annual consumption in 1973; about 65% is produced domestically. Most of the imported oil comes from Latin America and Canada which provide 22% of our needs for crude oil, nearly 40% of which is used to produce gasoline. Another 14% provides heating oil and kerosene. Power plants consume about 8.5% of the crude oil for production of electricity and about 11% is employed to produce gases such as propane for use as fuels and to produce petrochemicals such as plastics. The flow of crude oil and its use is shown in Figure 1-8.

Table 1-10. Comparison of Energy Growth Scenarios

	1973		1985						2000					
			Historical Growth		Technical Fix		Zero Energy Growth		Historical Growth		Technical Fix		Zero Energy Growth	
	Quads % Total		Quads % Total		Quads % Total		Quads % Total		Quads % Total		Quads % Elec. % Total		Quads % Total	
Residential	16.3	22	22.9	20	18.2	20	17.3	20	30.1	16	19.3	16	16	17.0 17
Commercial	10.4	14	15.1	13	13.8	15	14.5	17	21.3	11	16.9	14	14	18.8 19
Industrial	29.5	39	52.1	45	40.0	44	37.9	43	96.9	60	63.1	51	51	47.0 47
Transportation	18.8	25	26.0	22	19.6	21	18.4	21	38.4	21	24.7	20	20	17.2 17
TOTAL	75.0	100	116.1	100	91.3	100	65.2	100	186.7		124		100	100 100
Electric	6.4	8.5%	12.9	11%	8.0	8.8%	7.9	12%	27.1	14.5%	11.4		9.9%	11.5% 11.5%

Source: Ford Energy Policy Project.



Source: National Geographic, June, 1974

Figure 1-8. Sources and Uses of U. S. Oil in 1973

Of the 17.3 million barrels of crude oil per day consumed in 1973, 6.7 million bbl per day were used for gasoline. Distillate fuel oil use was 3.1 million bbl per day with nearly half (1.5 Mbbl per day) being used for heating oils (No. 1, 2, 4 oils), one-quarter for diesel fuel, and the remaining quarter for railroads, electric utilities and industrial uses. Residual fuel oil use was 2.8 Mbbl per day. The bulk of residual fuel oil was consumed by electric utilities: 1.4 Mbbl per day or nearly 50% of all residual fuel oil use. Low grade heating oils (No. 5 and 6) used 0.5 Mbbl per day or 18% of residual fuel oils, and industry consumed 0.4 Mbbl per day or 15%. The remaining 17% was used by oil companies in the refining process and for other miscellaneous consumption. Jet fuel use was 1.1 Mbbl per day with three-quarters being consumed by commercial airlines, and most of the remainder by the military. Liquefied petroleum gases and ethane consumption was 1.5 Mbbl per day. One-third was consumed in the form of propane (principally for farmers in crop drying), and half was consumed by the chemical industry for a variety of uses. Asphalt for roads accounted for 0.5 Mbbl per day. Table 1-11 summarizes the major demands for the various kinds of petroleum fuel stocks (Reference 1-11, pp. 17-31).

b. Natural Gas. In 1973 natural gas contributed 31% of the total U.S. energy use. This is 23.0 trillion cubic feet (CF) of natural gas or 23.0 quads per year. The daily average consumption of natural gas was 62.9 billion CF (BCF) in 1973; 8.6 BCF or 14% of this amount was lost in extraction, refining, or transportation. Of the remaining 54.3 BCF per day, 13.4 BCF or 25% was used in the residential sector; 6.3 BCF or 12% in the commercial sector; 24.0 BCF by industry, and 9.9 BCF or 18% by utilities for electricity production. The total value at the wellhead of natural gas in the U.S. was \$4.9 billion and 21.6 cents per MCF. These figures are summarized in Table 1-12 (Reference 1-11, p. 42).

c. Coal. In 1973 coal contributed 18% to the U.S. energy demand. Some 55.85 million tons (MT) of coal are used each year for domestic consumption which accounts for 14 of the 75 quads of annual consumption. The daily average consumption was 1.5 MT per day (an additional 0.14 MT per day are expected). The primary users of coal are electric utilities with 1.5 MT per day or nearly three-quarters of all coal consumption. Coke ovens and steel

Table 1-12. Major Demands for Natural Gas in 1973

	Daily Demand		Annual Demand	
	BCF	%	TCF	Quads
Residential	13.4	25	4.9	4.9
Commercial	6.3	12	2.3	2.3
Industrial	24.0	44	8.8	8.8
Electric Utilities	9.9	18	3.6	3.6
Other Customers	0.8	1	0.3	0.3
Total Delivered	54.4	86	19.8	19.8
Losses	8.5	14		
Total Consumption	62.9	100	23.0	23.0

Value at Wellhead 4.9
Billions of dollars

Average Price - Cents per MCF 21.6

Total Annual U. S. Consumption 75.0 Quads; Natural Gas = 31% of Total

Source: American Petroleum Institute, 1974.

Table 1-13. Major Demands for Coal in 1973

	Daily Demand		Annual Demand	
	MT	%	MT	Quads
Electric Power Utilities	1.06	69	387.0	9.67
Coke Plants	0.26	17	95.0	2.38
Steel and Rolling Mills	0.18	12	66.0	1.65
Retail Deliveries	0.03	2	11.0	0.27
Total	1.53	100	559.0	14.0
Exports	0614	-	51.1	1.38

Total U. S. Consumption = 75.0 Quads; Coal = 18.6% of Total

Source: American Petroleum Institute, 1974.

fuel inputs. Between 1968 and 1973 due to supply problems, the use of natural gas in electricity production declined as a percentage of the total. As a result of environmental pressures, percent coal use also declined. The result was that fuel oil use for electric production nearly tripled between 1968 and 1973 at an average annual growth rate of 24%. At least one author has attributed the energy crisis to this rapid switch to fuel oil for electricity production (Reference 1-2). Nuclear energy, which provided less than 1% of electricity in 1968 grew at an average rate of 41% to 1973 when it supplied 3.6% of the input for electric production as illustrated in Table 1-14.

Electrical production is a prime consumer of coal, requiring nearly 70% of the total annual coal production; 18% of natural gas is used to make electricity. As shown in Table 1-15, 22% of U.S. fossil fuel production is required to produce electricity.

The consumption of electricity is shown in Table 1-14, the largest consumer being industry which uses 44% of all electricity produced. Residential use is 31% and commercial 24%. The average growth rate of electricity is 7.3% for all sectors and 8.2% for the residential sector.

G. DEMAND-SIDE ENERGY SAVING OPTIONS: AN OVERVIEW

Having discussed U.S. energy demand, we are now in a position to examine demand-side energy saving options. These will include three different types of measures: (1) new or improved technology which is more efficient in its energy use, (2) different organizational arrangements which may reduce aggregate energy demand, and (3) consumer behavior change which will produce less consumer demand for energy. After reviewing these energy demand-reducing options, it will be possible to summarize the aggregate energy saving potential for demand-side actions.

1. New or Improved Technology and Improved Efficiency

New or improved technology can greatly reduce the demand for energy. Because of regulation, the prices of energy have been kept low. There has not

Table 1-14. Electric Power Consumption and Sources of Supply for 1968 and 1973

Electric Production Input		Average Annual			
	1968		1973		1968-1973 Growth Rate
	Quads	%	Quads	%	
Fuel Oil	1.1	7.7	3.2	16.0	24.0%
Natural Gas	3.2	22.0	3.6	18.0	2.4%
Coal	7.5	52.0	9.7	48.0	5.3%
Hydroelectric	2.6	18.2	2.9	14.0	2.2%
Nuclear	0.13	0	0.73	3.6	41.0%
Total	14.3 ^a		20.1		7.1%

Electric Power Consumption		Average Annual			
					1960-1968 Growth Rate
Residential	1.4	31.0	N/A	-	8.2%
Commercial	1.1	24.0	N/A	-	9.6%
Industrial	2.0	44.0	N/A	-	5.8%
Transportation	-	-	N/A	-	-
Total	4.5 ^a				7.3%

^aElectric power consumption is less than electric production because of the efficiency of conversion. The average power plant runs at 33% efficiency.

ORIGINAL PAGE 14
OF POOR QUALITY

Table 1-15. 1973 Fossil Fuel Use by Electric Utilities

Resource	1973			
	Resource	Percent of Resource	Quads	Percent of Fossil Fuel Input
Fuel Oil	577 Mbbbl	8.8	3.23	20
Natural Gas	3.6 TCF	18.0	3.61	22
Coal	388 MT	69.0	9.70	59
Total		-	16.5	100
Total energy consumption			75.0	22% of fossil fuels used for electric energy production.

been, therefore, an incentive to reduce energy consumption by spending money for improved techniques, which can be classified into two basic groups.

First, the basic efficiency of various energy using devices can be improved because the performance is quite low and highly variable. The U.S. Senate Committee on Interior and Insular Affairs estimated a variation of efficiency from less than 5% for the incandescent lamp to over 99% for large electric generators. Table 1-16 summarizes the efficiency of several common energy converters, and indicates an efficiency of 75% for natural gas space heating. Actually this is a maximum efficiency when the furnace is properly maintained and running at full load. The efficiency will be lower under less favorable operating circumstances. C. Berg of the National Bureau of Standards estimates that the typical residential furnace runs at efficiencies as low as 35-50% (Reference 1-12, p. 133). The Ford Foundation Energy Policy Project estimated a 0.9-quad annual saving by 1985 in improving the efficiency of residential space heating systems. The savings potential in industry for higher

Table 1-16. Maximum Efficiency of Selected Energy Converters End Use Sector

Fuel	Residential					Commercial			Industrial		
	Space Heating	Water Heating	Clothes Drying	Cooking	Air Conditioning	Space Heating	Water Heating	Refrigeration	Process Steam	Electric Drives	Electrolytic
Petroleum Products	63	50	--	--	--	76	50	--	68	--	--
Natural Gas	75	64	47	37	--	77	64		64	--	--
Coal	55	15	--	--	--	70	70	--	70	--	--
Electricity	95	92	57	75	50	95	92		--	90	15

Source: "Patterns of Energy Consumption in the United States," Stanford Research Institute, January 1972.

efficiency devices is even greater. By improving the efficiency of manufacturing in the five most energy-intensive industries (paper, steel, aluminum, plastics, and cement) a savings of 4.3 quads could be achieved by 1985.

Second, new technology can be used which inherently consumes less energy for the same work. The use of heat pumps rather than traditional heating and cooling devices in buildings could save 2.5 quads annually by 1985. Each sector has potential applications for improved efficiency devices and the use of new technologies. Table 1-17 presents the energy savings potential in each of the major sectors. Table 1-18 shows the energy savings potential by energy saving type, and from "improved efficiency" and "use of new technology" which is 11.6 quads in 1985 producing about a 10% reduction from the 1985 historical growth energy demand requirements of 115 quads.

Another important source of inefficiency which produces high energy consumption occurs in transportation. The basic energy efficiency per mile is quite different depending on the mode of transportation. On a Btu/mile basis, jet airplane travel requires six times more energy than a highway bus. (There are, of course, travel time differences which must be considered in addition to the basic Btu/mile energy efficiency). The SST requires nearly twice the energy per mile than that used by the jet airplane. The basic efficiency of automobiles, buses, motorcycles, trains, and airplanes is shown in Figure 1-9. The efficiency of each mode is a function of the average number of passengers assumed to use the mode.

2. Organizational Arrangements

Altered organizational arrangements are a second major way of reducing energy demand. This type of solution can range from the widespread use of car pools to an integrated community trash disposal and energy system which uses the wastes. Special car pooling and bus lanes have been set aside on several freeways across the country to encourage the use of more energy-efficient modes of transportation. Estimates of the savings to be gained are tenuous because of the uncertainty of consumer behavior given the altered

ORIGINAL PAGE IS
OF POOR QUALITY

Table 1-17. Energy Savings Potential by Sector

Sector	Energy Saving Method	SAVINGS	
		1985 Quads	2000 Quads
Residential	Improved building design, insulation	1.3	3.7
	More efficient space conditioning systems	0.9	2.1
	Widespread use of solar energy	0.5	1.5
	Heat pumps	1.8	3.4
	Other	0.7	1.0
	Total	5.2	11.7
Commercial	Improved building design, insulation	0.7	1.4
	Total energy systems	0.1	1.5
	Heat pumps	0.6	1.7
	Other	-	0.3
	Total	1.4	4.9
Industrial	Improved efficiency in big 5 mpg	4.3	13.1
	On-site producing electricity and steam	0.5	3.5
	Use of recuperators and direct fuel for heating	2.9	5.4
	Other	2.5	7.4
	Total	10.2	29.4
Transportation	Auto - fuel economy to 25 mpg by 2000	5.9	9.9
	Air - increase load factor to 67% reduce flight speeds 6% short run passengers to rail	1.3	4.1
	Trucks - shift intercity freight to rail	0.2	2.2
	Other	-	-
	Total	7.4	16.2
Historical growth energy projection		115	185
Total savings (all sectors)		24.2 21%	62.2 34%
Energy use with conservation		92	123

Source: Ford Foundation Energy Policy Project.

Table 1-18. Energy Savings by Type for all Sectors

Savings Type, All Sectors	Savings	
	1985 Quads	2000 Quads
Improved Efficiency	5.2	16.8
Use of New Technology	6.4	17.0
Heat pumps	2.4	5.1
Solar energy	0.5	1.5
Total energy systems	0.6	5.0
Recuperators	2.9	5.4
More Efficient Building Design	2.0	4.1
Change in Use Patterns	1.5	6.3
Air load factors		
Shifting to rail		
Automobile Changes	5.9	9.9
Miscellaneous	3.2	8.4
Total Savings	24.2	62.5

Source: Ford Foundation Energy Policy Project.

ORIGINAL PAGE IS
OF POOR QUALITY

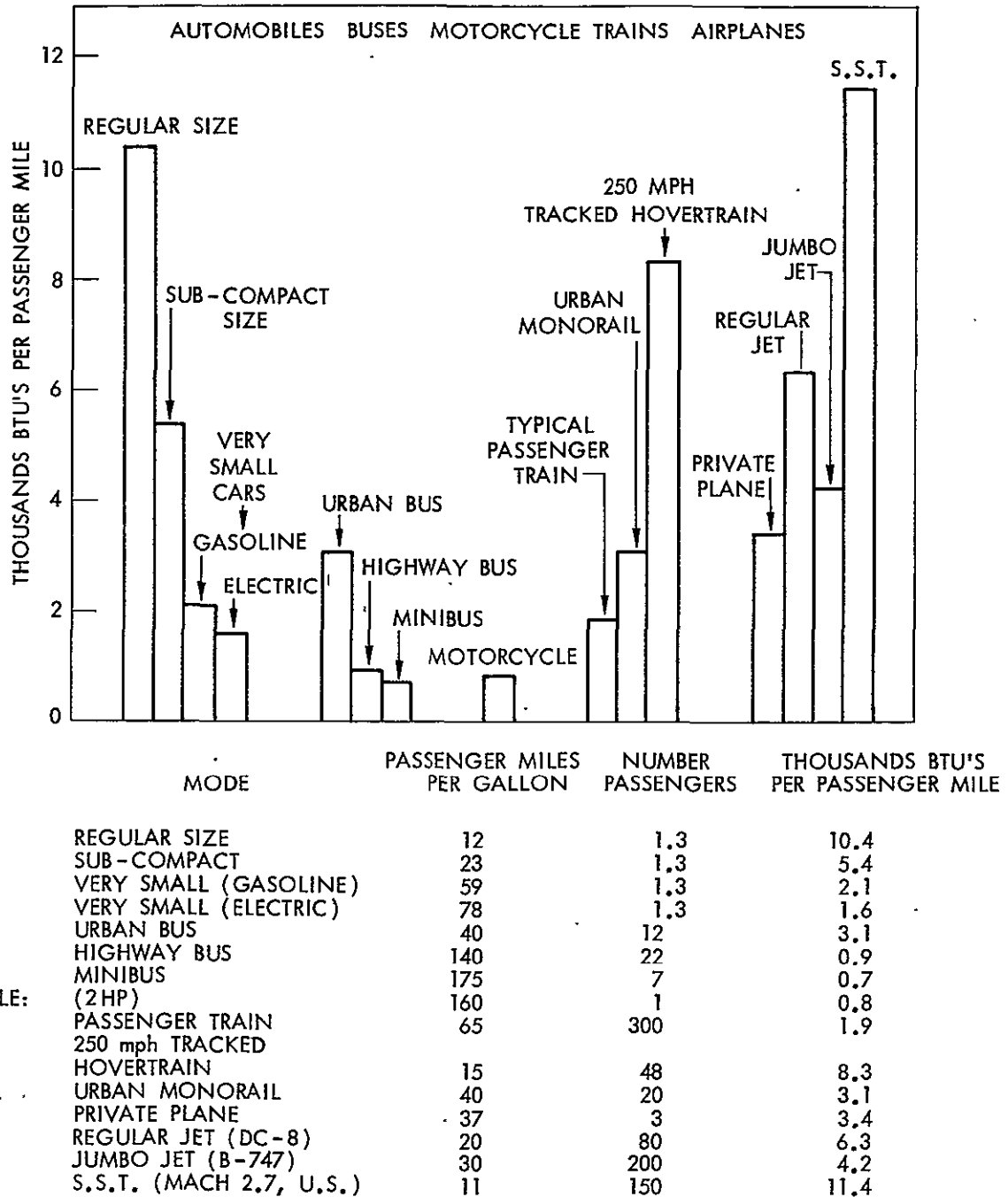


Figure 1-9. Transportation Energy Consumption of Various Modes

institutional arrangement. A study by Shell Oil indicates that car pooling could save 1.5 quads per year by 1985 (or the equivalent of about 3/4 million bbl oil/day). Complete cycle energy systems using municipal trash have been built on a community basis. One such site was constructed under the HUD Operation Break Through Program in Jersey City, New Jersey. The commercial potential for such installations is limited by the problems of developing comprehensive plans on a community level. Nonetheless, the potential energy savings from this type of system are technically feasible and could save a large amount of energy.

A shift in use patterns away from short airline flights to intercity rail and away from long haul truck freight to long haul rail freight could save 1.5 quads annually by 1985 and 6.3 quads by 2000. This would require overhaul of the ICC and CAB regulatory policies. Viewed as an institutional arrangement, these policies have promoted inefficient energy use in transportation. In order to maintain accessible airplane schedules, airlines have been regulated so that their average load factor is only about 50%. Increasing this to 67% would save nearly 1.0 quads annually by 1985. Similarly, the highway building program and ICC regulations have promoted inefficient use of trucking at the expense of rail traffic. Estimates are that most trucks are incurring over \$150 more in highway cost than they are paying in gasoline taxes (Reference 1-13, p. 672). An alteration of these policies with a concurrent change to the more energy-efficient mode would save 2.2 quads by 2000. In all, the change in use patterns induced by careful alteration of institutional arrangements could save a substantial amount of energy.

3. Consumer Behavior Changes

Consumer behavior changes can greatly affect energy demand, and can occur in a variety of ways. First, price in a competitive market can have a strong impact on consumer behavior. The response to price change is represented in economics by the elasticity of a commodity. Demand elasticity measures the percentage change in demand which will accompany a 1% change in the unit price of a commodity. If a large change in price produces only a small change in the total demand, then the demand is inelastic. Until the

Embargo of 1973 many observers believed that gasoline demand was relatively inelastic (Reference 1-14). Evidence since the Embargo indicates that consumers have cut back their use of gasoline in response to higher prices. In 1974 gasoline use was 3.9% lower than in 1973 — the first annual decrease in gasoline use since 1943 (Reference 1-15). The FEA estimates that two-thirds of the reduced crude oil use in 1974 and 1975 was produced by consumer elasticity. (The remaining one-third was produced by a general economic slowdown). The Hudson-Jorgenson econometric model estimates a demand elasticity of -0.15 for prices in the \$7-\$11/bbl range (Reference 1-16). Using this estimate, Brannon has calculated a demand reduction of 3.8 million bbl/day (or 8.1 quads annually) in 1980 if prices on domestic crude oil are allowed to rise to \$11/bbl.

A second method of producing consumer behavior change is by providing the consumer with the appropriate information. Because of the knowledge required to make economic tradeoffs concerning energy conserving options, there is a cost to the consumer of considering said changes. This "information cost" is one of the frictional impediments in the marketplace and results in a less than optimum allocation of resources and hence economic waste. Such a situation provides ample justification for government involvement (Reference 1-17). Information on feasible energy conserving measures and the cost and benefits of their use could be provided to consumers through publicly funded energy outreach programs. There is ample evidence from the experience of the USDA cooperative extension and other sources that such programs are cost effective they are user- and problem-solving oriented rather than technology-sales oriented (Reference 1-18).

The process of consumer behavior change is complex and beyond this discussion, but the energy savings potential of altered consumer behavior with respect to technology is quite large. For example, lowered thermostat settings in buildings offer a great energy saving potential. If home owners would set back their thermostats by 10 deg at night, the savings would be 10-15% or about 0.75 quads annually (Reference 1-19, p. 41). Reducing thermostat settings by only 2 °F (e. g., from 72 °F to 70 °F in the winter) would produce a 0.6-quad annual saving (Reference 1-20, p. 25).

Automobile transportation provides another good example of energy savings potential from altered consumer preferences. A switch to smaller, lighter automobiles which increase the average efficiency from current 13 mpg to 20 mpg in 1985 and 25 mpg in 2000 would save 5.9 quads annually in 1985 and 9.9 in 2000. Although some of this change will be produced by technology, the largest changes are produced from a switch to lighter and smaller cars which will require consumer acceptance to be viable.

4. Summary

Having discussed the various demand-side conserving options, it is now possible to summarize the savings potential. The summary of savings estimates will be given sector-by-sector and for all sectors in aggregate. Without any measures to reduce demand, it is likely that energy consumption will grow from 75 quadrillion Btus in 1973 to over 116.1 quadrillion Btus by 1985, and 186.7 quadrillion Btus by the year 2000. Table 1-19 summarizes the Ford Energy Policy Project estimate of energy consumption in a historical growth scenario. This growth will occur even if the annual growth rate in primary energy use drops from the 4.8% experienced between 1960 and the early 1970s to what is now estimated to be a more reasonable growth rate of 3.4%/year in the decades ahead. Because the absolute size of our current energy consumption is now quite large, the continuation of historical growth means addition of larger and larger absolute amounts of supply capacity each year. "It means adding each year new energy production equivalent to 1.3 million barrels of oil per day in 1975, 2.0 in 1985, and 3.3 in the year 2000. By 1985 this would be equivalent to adding one new Alaskan pipeline each year" (Reference 1-10, p. 20). The main consuming sector is industry which increases its fraction of energy consumption from 39% in 1973 to 52% by the year 2000. All other sectors decline in importance compared to the industrial sector.

The projected energy demand reduction will be significant in each of the end use sectors--residential, commercial, industrial, and transportation. Ways of saving energy in the transportation sector include three primary areas: auto, air transportation, and trucks. About 6 quadrillion Btus could

Table 1-19. Energy Savings by Demand Reduction by Sector

	1973 Consumption	1985 SAVINGS				2000 SAVINGS			
		Historical Growth	Quads	%	Technical Fix	Historical Growth	Quads	%	Technical Fix
Residential	16.3	24.0	5.2	22	19.0	32.0	11.7	37	20.0
Commercial	10.4	16.0	1.4	9	15.0	23.0	4.9	21	18.0
Industrial	29.5	46.0	10.2	22	36.0	87.0	29.4	34	58.0
Transportation	18.8	29.0	7.4	26	22.0	43.0	16.2	38	27.0
TOTAL	75.0	115.0	24.2	21	92.0	185.0	62.2	34	123.0

Note: Numbers given in A Time To Choose are in conflict.

Source: Ford Foundation Energy Policy Project.

ORIGINAL PAGE IS
OF POOR QUALITY

be saved annually by 1985 and almost 10 quadrillion by 2000 by improving automobiles and fuel economy from the current 13 mpg to 20 mpg in 1985 and 25 mpg by 2000.

The Ford Energy Policy Project estimates that the increase in the fuel economy from 20 mpg could be produced by fairly simple means: 1) aerodynamic drag reduction through body redesign - 5% improvement; 2) rolling resistance reduction through use of radial tires - 10% improvement in efficiency; 3) better load to engine match - 10 to 15% improvement; and 4) substitution of 300 lb of aluminum for 1,750 lb of steel - 18% improvement.¹

¹ While the manufacture of aluminum requires much more energy than manufacturing steel, the substantial net energy savings is possible by substituting aluminum for steel. Operating the lighter weight cars saves about 17 times the extra energy required to make the aluminum (Reference 1-10, p. 59).

Improvements in air transportation can be produced by increasing passenger load factors to 67%, reducing flight speed to 6% and shifting shorter run traffic to rail. Savings from trucking would accrue by shifting from gasoline fuel trucks to diesel and also shifting of intercity traffic to rail. This would require about 20% shift by 1985 and 40% by 2000. The total savings by 1985 would be 7.4 quadrillion Btus in 1985 and 16.2 quadrillion Btus by 2000. This is shown in Table 1-20 which indicates a 22% reduction in the projected energy use in transportation by 1985.

For the industrial sector, substantial energy savings could accrue from savings in the five energy intensive industries which use predominantly most of the energy in the industrial sector. Together these industries require about 33.8 quadrillion Btus by 1985 and 62.4 in 2000 of the total 87 quadrillion Btus estimated to be necessary by the year 2000. More efficient production processes in paper, steel, aluminum, plastics, and cement manufacturing could save 4.3 quadrillion Btus by 1985 and 13.1 by 2000. The use of heat recuperators and regenerators with direct use of fuels instead of electric resistive heat could save 2.9 quadrillion Btus by 1985 and 5.4 by 2000. The strategies for saving energy in industry are well documented by the Ford Foundation Energy Policy Project.

For residential and commercial sectors, substantial energy savings can accrue primarily through the use of insulation against heat loss for space heating and against heat gained for air conditioning, the use of heat pumps instead of resistance heat for space heating, and the use of solar energy for heating and water heating. Combined, these savings could reduce residential energy use by 22% in 1985 compared to the historical growth case, and 37% by 2000. Although energy is reduced from the historical growth projections, total energy consumption will increase. The rate of increase will be dramatically slower.

In aggregate, energy consumption under these demand reduction strategies will yield a 20% reduction in demand by 1985 and a 34% reduction by 2000. Even so, energy consumption will increase from 75 quads in 1973 to 123 quads in 2000 or at an average of 1.8%/year. Although demand-side actions alone

Table 1-20. Historical Growth Scenario of Energy Use

	1973		1985		2000	
	Quads	%	Quads	%	Quads	%
Residential	16.3	22	22.9	20	30.1	16
Commercial	10.4	14	15.1	13	21.3	11
Industrial	29.5	39	52.1	45	96.9	52
Transportation	18.8	25	26.0	22	38.4	21
TOTAL	75.0		116.1		186.7	

Source: Ford Foundation Energy Policy Project.

will not eliminate the energy problem, neither will supply-side actions alone. In fact, the energy dilemma is so complex that its solution will require the conscious orchestration of many energy options. Changes of a few percent in the annual growth rate of energy can make a substantial alteration in the energy dilemma because of the compounding effect of even small percentage reductions. Further, no single source or demand-side conservation activity will solve the problem alone. We face a national dilemma in which the solution requires simultaneous use of a variety of options. In this context, solar energy can make a significant contribution. Further insight into this fact can be obtained by examining the current mismatch between domestic energy supply and demand.

The causes of the U.S. energy dilemma can be analyzed in a variety of ways. One useful way is to view it as resulting from the mismatch between the growth rate of demand for energy and the growth rate of domestic supplies of energy (Reference 1-21). In the decade preceding the Oil Embargo of 1973,

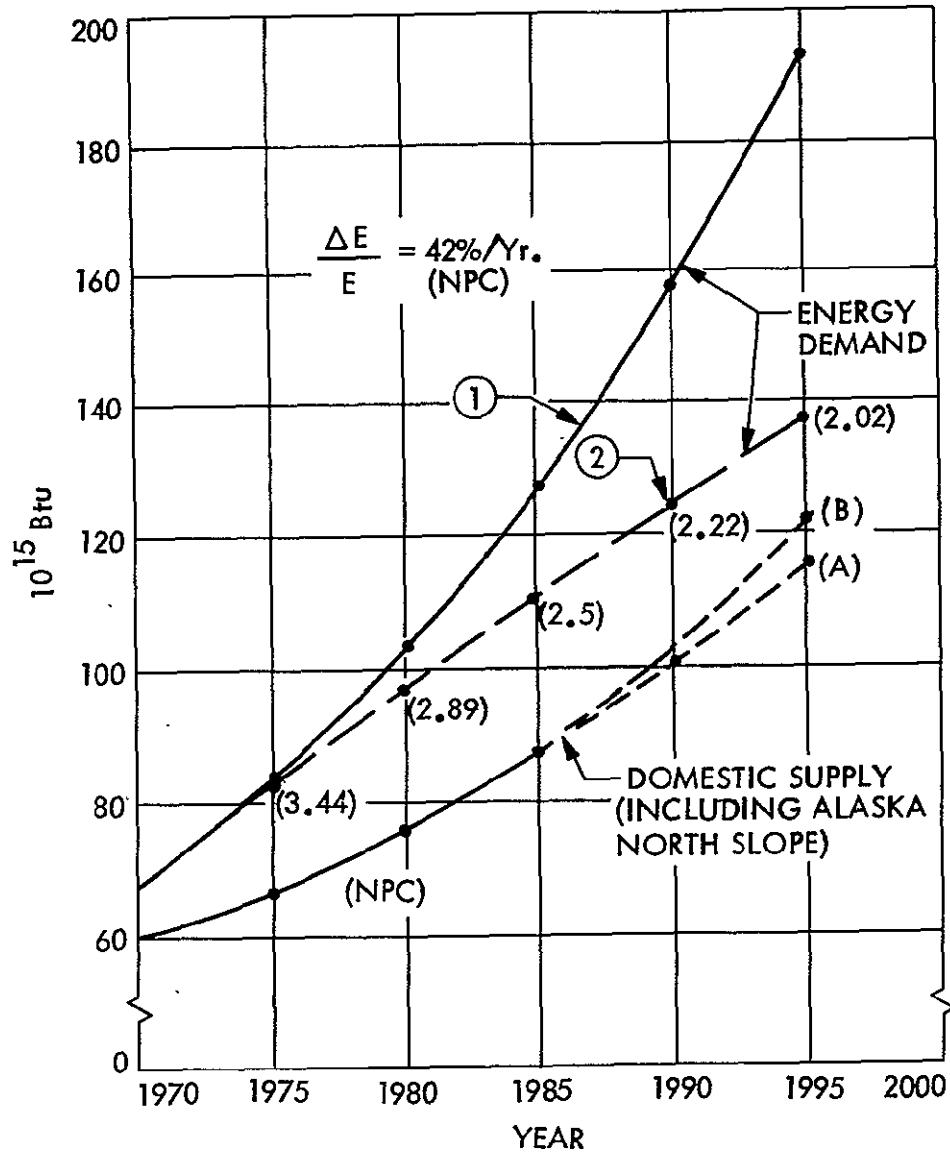
domestic demand for energy grew at about 4.2% annually while domestic supplies grew at about 2.6%. These growth rates are shown in Figure 1-10 prepared at the Environmental Quality Laboratory at California Institute of Technology. The upper curve (labeled 1) shows the 4.2% growth in primary energy demand as projected by the National Petroleum Council. The curve labeled 2 shows demand growth under a strategy of slowly lowering the growth rate from 4.2% to 2.02% by 1995. The lower curves labeled A and B show the 2.6% growth in primary energy supply (principally fossil fuel) as projected by the National Petroleum Council.

By comparing the lower curves (A and B) with the upper curves (1 and 2), the dramatic effect of the mismatch in the growth rates of supply and demand can be seen. The difference between these upper and lower curves is the net domestic energy shortfall and is the annual value of the mismatch which must be made up through imports (or other measures). The curve labeled 1-A in Figure 1-11 presents this mismatch as projected by the National Petroleum Council both in terms of energy requirements and the number of tankers required to provide this domestic energy shortfall. As Lees (Reference 1-22) pointed out:

...the precipitous increase in the number of large oil and liquid natural gas (LNG) tankers of 250,000 dead-weight tons (DWT) each that would be required to transport these imports to the United States, to say nothing about the number of U.S. deep-water ports that would be needed to handle this enormous tonnage. The environmental impact of oil spills and dredging operations on this scale is difficult to contemplate.

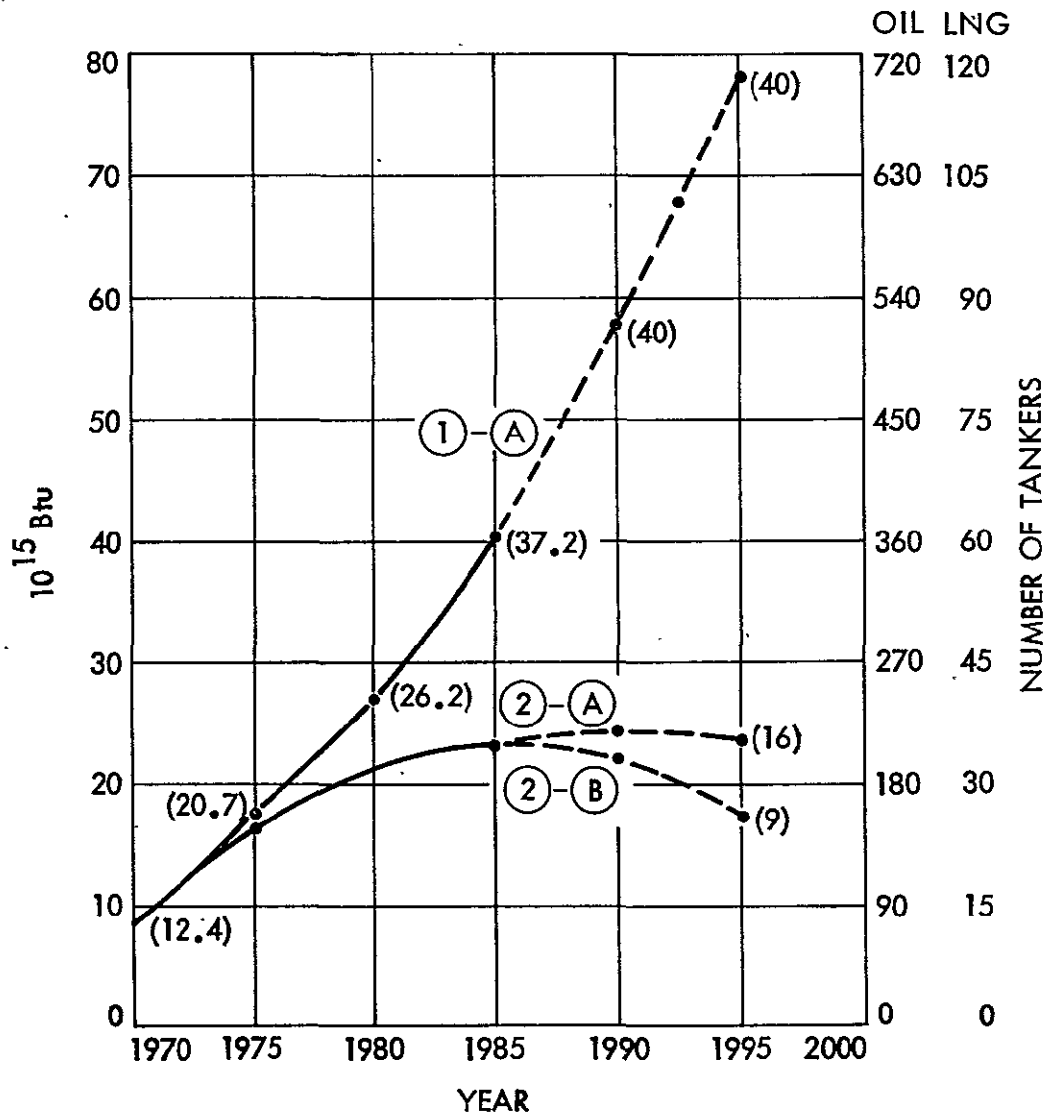
Yet, the National Petroleum Council (NPC), perhaps the most authoritative group on the subject of petroleum company activities and policies, apparently failed to understand the significance of their own projections. This represents, I believe, paradigm lock in the strongest sense. The NPC had always looked at its job as promoting increasing use of petroleum and finding new ways to meet the resulting increase in demand. Apparently prior to fall of 1973, few members of the Council ever questioned their ability to obtain new supplies of petroleum indefinitely. Few even questioned the implied logistical and political problems concerning delivery of foreign supplies of petroleum. No one in the

ORIGINAL PAGE IS
OF POOR QUALITY



Source: Lees, 1972.

Figure 1-10. Annual U.S. Primary Energy Demand and Domestic Supply - Two Projections



Source: Lees, 1972.

Figure 1-11. Annual U.S. Primary Energy Imports and Total Number of Tankers Required (250,000 DWT) - Three Projections

NPC called for conservation or at least "managed" growth like that suggested at EQL even though the results of management of the growth rate can have a dramatic effect in reducing the mismatch from an exponentially increasing dilemma to a more moderate energy shortfall. The curve labeled 2-A shows the results of a managed growth rate reduction from the current 4.2%/year to 2%/year growth in 1995. The result is qualitatively as well as quantitatively different in terms of oil import requirements.

It is in this context that solar energy may help us manage the impact of the energy dilemma. The curve labeled 2-B in Figure 1-11 shows the impact of solar energy (growing from 0 to 6×10^{15} Btus from 1985 to 1995) included in the management strategy after 1985. With solar energy, the requirement for energy imports peaks in 1985 and then falls. Without solar energy, the managed growth curve (2-A) flattens out in 1985 and remains constant.

In summary, this mismatch in the growth rates of supply and demand can be cured in one of two ways. First, new supplies of energy can be developed which allow supply to grow in tandem with demand. The development of new domestic oil and coal reserves, nuclear power, fusion, geothermal and large scale solar energy all fall into this category. Unfortunately, the development of these new sources or supplies of energy require either long lead times on the order of 10-15 years before the technologies are developed or the abandonment of environmental standards.

A second way to eliminate the mismatch is to develop methods of reducing the growth in demand for energy. These demand-side actions include several categories of energy conservation and renewable resource development and, as shown in curve 2-B in Figure 1-11, can have a dramatic impact on the energy dilemma. The potential value of low temperature solar thermal applications for heating and cooling of buildings can be best analyzed in this category of demand-side actions because solar energy is a renewable energy source, the technology is either available now or requires relatively short-term development and solar energy poses few, if any, environmental hazards. Before examining the potential for solar energy in this context and the implementation and policy issues which must be addressed, it is necessary to review the supply-side options of U.S. energy use. Understanding the basics of

supply-side energy options will help us understand what will make a difference both for reducing the mismatch and for the potential role of solar energy.

H. SUPPLY-SIDE ENERGY OPTIONS: AN OVERVIEW

Supply-side energy options fall into two categories — minerals such as fossil fuels, and technologies for utilizing minerals or renewable resources. The important energy-related minerals are coal, petroleum, and natural gas. These are burned to produce direct energy for the various end uses discussed in the early part of this report. The technologies include those which are used to capture renewable energy sources for conversion to useful work such as hydroelectric dams and technologies which convert minerals into alternate useful forms such as coal gasification. This abbreviated discussion will examine each of these supply-side options.

1. Minerals

The U.S. is richly endowed with energy resources; its land mass comprises about 1/17 of the world land mass, and contains approximately 1/4 of the coal, 1/7 of the petroleum, possibly 1/10 of the natural gas, 1/12 of the oil shale, and 1/17 of the uranium and thorium (Reference 1-23).

The mineral energy sources are measured in terms of the individual base of each mineral. These mineral fields exist in different parts of the U.S. and are of varying quality. Some fields have concentrated deposits, others contain less. At any given time some of the deposits have been well studied and are developed for production. Others are known, but for one reason or another remain undeveloped. Still others are unknown. In order to develop a deposit, an investment must be made in extraction equipment. Minerals which have been developed for profitable production are called reserves (Reference 1-10, Chapter 4).

Reserves are a measure of the current profitable developed minerals in the ground. As minerals are withdrawn, reserves decline. As exploration finds new, economically developable deposits, new reserves are added to the inventory. Reserves are often measured in terms of reserve-to-annual production ratio which is the number of years that the inventory would last at the

given production rate if no new discoveries were made. "Economic forces keep the reserve-to-production ratio for many minerals at something like 10-20 years" (Reference 1-10, p. 29). Larger ratios tend to be uneconomical because of the required capital investment necessary to expand the ratio. The reserve-to-production ratio will be influenced by changes in interest rates and other economic factors which impact capital allocation. Therefore, a drop in the ratio does not necessarily signal approaching depletion of a mineral resource, but may indicate a rise in interest rates or a regulatory policy which restricts the return on mineral development to a level lower than some other investments.

Deposits which are known but undeveloped are often called submarginal, because they cannot be developed to produce a profit under the prevailing technology and economic situation. An oil well provides an excellent example of this. When an oil field is first developed, initially the oil flows easily. As more oil is withdrawn, the oil flow slows down. When the cost of extracting the next barrel of oil from the field exceeds the price that can be obtained from its sale, all of the reserves are gone. "Yet 70 percent or so of the original oil in place in the field still remains there as a submarginal resource" (Reference 1-10, p. 29). As new recovery technology is developed or the price of oil rises, there comes a time when some of the remaining oil can be recovered profitably. This creates new reserves which are, therefore, a function of price and recovery technology.

Also, at any given time additional mineral deposits exist which are undiscovered. Once discovered, some of these deposits will be economically recoverable and hence added to reserves. The quantities of reserves submarginal resources, both known and unknown, form the basis of estimates of the future energy supply situation. Although undiscovered deposits are clearly difficult to determine, geologists and other experts are able to make reasonable estimates of their size.

Figure 1-12 will help to classify mineral deposits — those which are both recoverable economically and known are termed "reserves." All other deposits

	KNOWN	UNDISCOVERED
RECOVERABLE	RESERVES	
SUBMARGINAL		RESOURCES

Figure 1-12. Classification of Mineral Resources

are classified as "resources." The U.S. Geological Survey and others have made estimates concerning the reserves and resources of the various important energy minerals in the United States. For various reasons these estimates are often subject to wide variation. Table 1-21 is a compilation of the estimated reserve projections made by three different groups.

The top part of the table summarizes the situation for fossil fuels (petroleum, natural gas, coal, and oil shale). The reserve estimates for petroleum, natural gas, and coal are in reasonably close agreement. The oil shale estimates differ widely, reflecting each author's different assumption concerning oil shale technology and extraction costs. Of the three estimates, the lowest of total fossil fuel reserves is 6750 quads. U.S. annual energy consumption in 1973 was 75 quads. Assuming no demand-side energy reducing actions, annual consumption could rise to 186 quads by 2000. Taking the average annual consumption rate during this 27-year period which is 130 quads/year, and assuming no additions to reserves, our known fossil fuel reserves should last well into the 21st century (Table 1-22).

Of course, reserves are not the complete index of potentially recoverable minerals. Additional resources are also important. Table 1-23 summarizes Fisher's estimates of fossil fuel reserves and resources. The total is 250,000 quadrillion Btus. Cumulative fossil fuel consumption through 1973 has been about 2000 quads (1000 quads coal, 660 quads oil, and 360 quads gas).

Table 1-21. Estimates of U.S. Reserves

	Ford EPP, Quads	D. White MIT, Quads	J. Fisher G.E., Quads
Petroleum	410-530	300	300
Natural gas	440-570	300	300
Coal	5,000	9,000	9,000
Shale oil	<u>900-3400</u>	<u>4,000</u>	<u>—</u>
Total Fossil Fuel	6750-9500	13,600	9,600
Uranium			
Thermal	310	280	220
Breeder	22,000	500,000	16,000
Solar Input			
Above atmosphere			530,000/yr
At ground			45,000/yr
Annual U.S. Energy Use 1973 = 75 Quads			

Table 1-22. United States Fossil Fuel Reserves and Resources

Fossil Fuel	Reserves	Additional Resources
Coal	9,000	66,000
Petroleum	300	16,400
Natural gas	300	6,400
Shale oil	<u>300</u>	<u>150,000</u>
	9,600	240,000

ORIGINAL PAGE IS
OF POOR QUALITY

Table 1-23. Total United States Reserves and Resources

Energy Source	United States Reserves	United States Additional Resources
Fossil fuels		
Coal	9,000	66,000
Petroleum	300	16,400
Natural gas	300	6,400
Shale oil	—	<u>150,000</u>
Total	9,600	240,000
Nuclear fuels with breeder technology		
Uranium	11,000	220,000,000
Thorium	<u>5,000</u>	<u>340,000,000</u>
Total	16,000	560,000,000
Nuclear fuels with conventional technology	220	4,400,000
Source: Fisher.		

Assuming that U.S. energy consumption stabilizes in a century or two, at three times the average annual consumption rate in the unmodified demand (historical growth) scenario, the U.S. possesses enough fossil fuel resources and reserves for over 600 years = $\frac{250,000 \text{ quads reserves and resources}}{390 \text{ quads/year consumption}}$.

The reserve and resource estimates for uranium and thorium, both used in nuclear fission reactors, have been made by the federal government. The estimates are highly dependent on nuclear technology which utilizes the ore. Current nuclear technology (light water reactors) utilizes about 1.5% of the energy potential of uranium. Breeder technology is projected to utilize nearly 80% of the energy potential of uranium. The impact of breeder technology is quite dramatic as can be seen in Table 1-24. Uranium reserves with current technology are limited to 220 quads. The use of the breeder reactor increases the reserve 80-fold to 16,000 quads.

Table 1-24. Cost Comparison of Different Fuels and Solar Energy

Fuel	Units	Btu Value per Unit	Cost per Unit	Conversion Efficiency (%)	Net Cost with Conversion \$/10 ⁶ Btu	Approximate Average 1975 Unit Price	Net Cost (Inc. Efficiency) \$/10 ⁶ Btu
Crude Oil	Barrel (bbl)	5,800,000	10\$/bbl	100	1.72	13\$/bbl ⁽¹⁾	2.24
	Gallon (gal)		(.24\$/gal)	60	2.87		3.74
				30			7.47
Natural Gas	1000 Cubic Feet (cu ft)	1,032,000	1\$/cu ft	100	1.00	2.50\$/cu ft ⁽²⁾	2.50
				60	1.67		4.17
				30	3.33		8.33
Coal	Ton (t)	24,000,000	20\$/ton	100	0.83	30\$/ton ⁽³⁾	1.25
				60	1.39		2.08
				30	2.78		4.15
Electricity	Kilowatt-hour (kWh)	3,413	1¢/kWh	100	2.93	3.5¢/kWh ⁽⁴⁾	10.25
				90	3.23		11.39
Solar Energy	Square Foot (ft ²)	510,000 per yr	\$20/ft ²	30		8%, 20 yr loan ⁽⁵⁾	13.00
			\$10/ft ²	30			6.50

(1) Decontrolled domestic oil and OPEC posted oil price December 1975.

(2) Intrastate natural gas and estimate of market clearing price without controls.

(3) Approximate spot price for low sulphur coal.

(4) Residential 3rd block vote in California. Pacific Northwest is lower (1.5¢/kWh) and New England higher (7.50¢/kWh).

(5) A 15%, 10 yr. loan will double net cost.

Space heating furnaces are listed at 75% efficient, however, often they are found to be 35-50% efficient. The BASE project measured a 57% efficiency on a typical hour.

Coal fired plants run at an average of 35-40% efficiency (Reference 1-12, p. 135).

C. Berg, "Energy Conservation Through Effective Utilization", National Bureau of Standards, 1972, unpublished.

ORIGINAL PAGE IS
OF POOR QUALITY

In addition to minerals, basic energy resources should include renewable resources such as solar and geothermal energy as well as nuclear fusion. Solar energy is provided by the continuous solar flux. About 5,300,000 quads reach the upper atmosphere per year. At the equatorial ground level approximately 1 million Btu fall on a square foot/year. In the United States the average isolation is about half of this. If the total 1973 U.S. energy consumption of 75 quads was obtained from solar energy at 10% conversion efficiency, an area of about 60,000 square miles would be needed. This is equal to about 3-1/2% of all the land devoted to farms. Hydropower is limited by the number of streams and rivers. According to Fisher, the total hydropower resource base is about 10 quads annually for the U.S. and 90 quads for the entire world. The geothermal heat reserves are about 2,500 quads with an additional 10 million quads potential resource. Fusion resources are virtually unlimited.

In a sense, the ultimate energy source on earth is the sun. With the exception of nuclear, geothermal, and gravitational energy, all energy sources including fossil fuels are derived from the sun. This can be understood by examining the total solar radiation flow (see Figure 1-13, Reference 1-24, p. 16). Of the 530,000 quads/year which fall on the upper atmosphere, 30% is reflected directly back into space, 47% is converted directly into heat and reradiated as infrared energy, 23% is used to evaporate water producing rain and snow and to drive the winds, the remaining small amount is used by plants in photosynthesis. As the plants decay or are eaten by animals who decay, this organic energy is stored in fossil fuels.

Given this plethora of energy resource base, it is fair to question whether an energy crisis or even a dilemma exists. After all, even without nuclear power we have enough fossil fuel reserves in the form of coal to last several hundred years. The development of breeder reactors will make available a resource base four times greater than the coal base, and the development of either solar or fusion technology would provide a limitless supply of energy. So where's the problem?

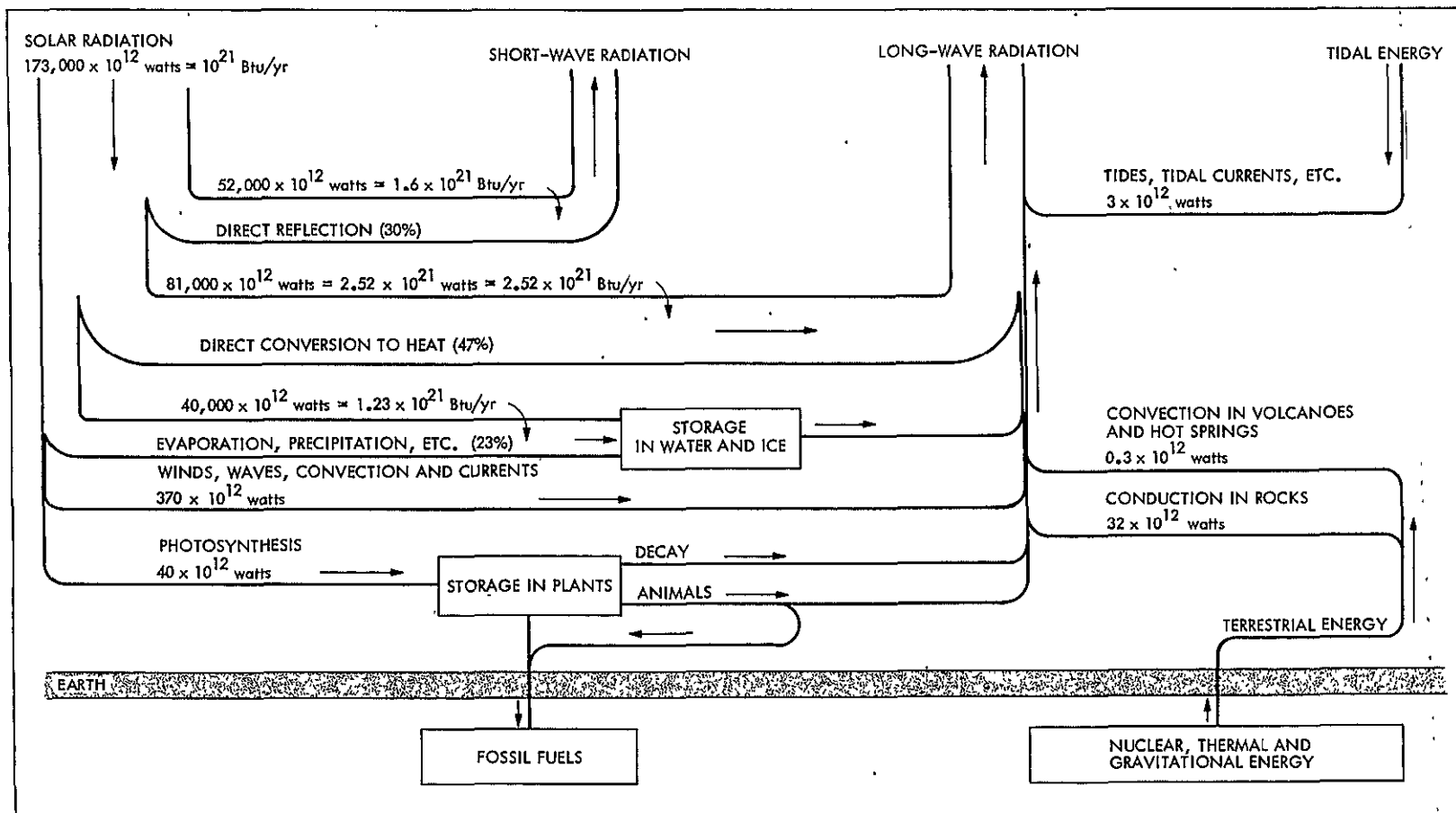


Figure 1-13. Total Solar Radiation Flow

2. Summary

The energy crisis is not a crisis of ultimate resource shortage. Despite the popularity (and partial wisdom) of the "limits-to-growth" arguments, we are in no imminent danger of depleting our total energy resources. We are facing a crisis of four sorts, however.

First, we face a depletion of our most easily used energy forms (oil and natural gas) around which our economy and life-styles have been built. King Hubbert in a classic work nearly 10 years ago demonstrated that we were rapidly passing through the petroleum age. By analyzing new petroleum discovery rates, Hubbert predicted that domestic oil production would peak about 1971 and decline thereafter (Figure 1-14). Using an ultimate recovery resource base for petroleum of 200 billion bbl or 1,160 quads, he predicted that U.S. petroleum production by 1985 would decline to roughly 1940 levels of production, and reach virtual depletion by 2060. Furthermore, he demonstrated that even if the total undiscovered recoverable resource was higher, that the reality and timing of the depletion curve would not be altered. His work showed that 80% of the recoverable petroleum would be exhausted in a span of 58 to 64 years beginning around 1950 (Figure 1-15). One way to view the energy dilemma is to see us as having to switch rapidly from a petroleum-based economy to alternate energy sources. The unique properties of petroleum will have to be foregone.

Second, the energy dilemma is a question of time frame. We have enough domestic coal to last 300 years but our immediate problem is how to manage the transition period from 1975 to 2000. The long term availability of alternatives is no solution for the potential short and intermediate term economic and social problems of the next two decades. With the historical rapid growth in demand, the rapid shift is socially treacherous.

Third, the question of solution is as much an economic problem as a technical or geological one. Our previous energy producing experience has generally been a reduction in energy prices over time. Figure 1-16 shows the experience curve of petroleum production in the United States. The trend line

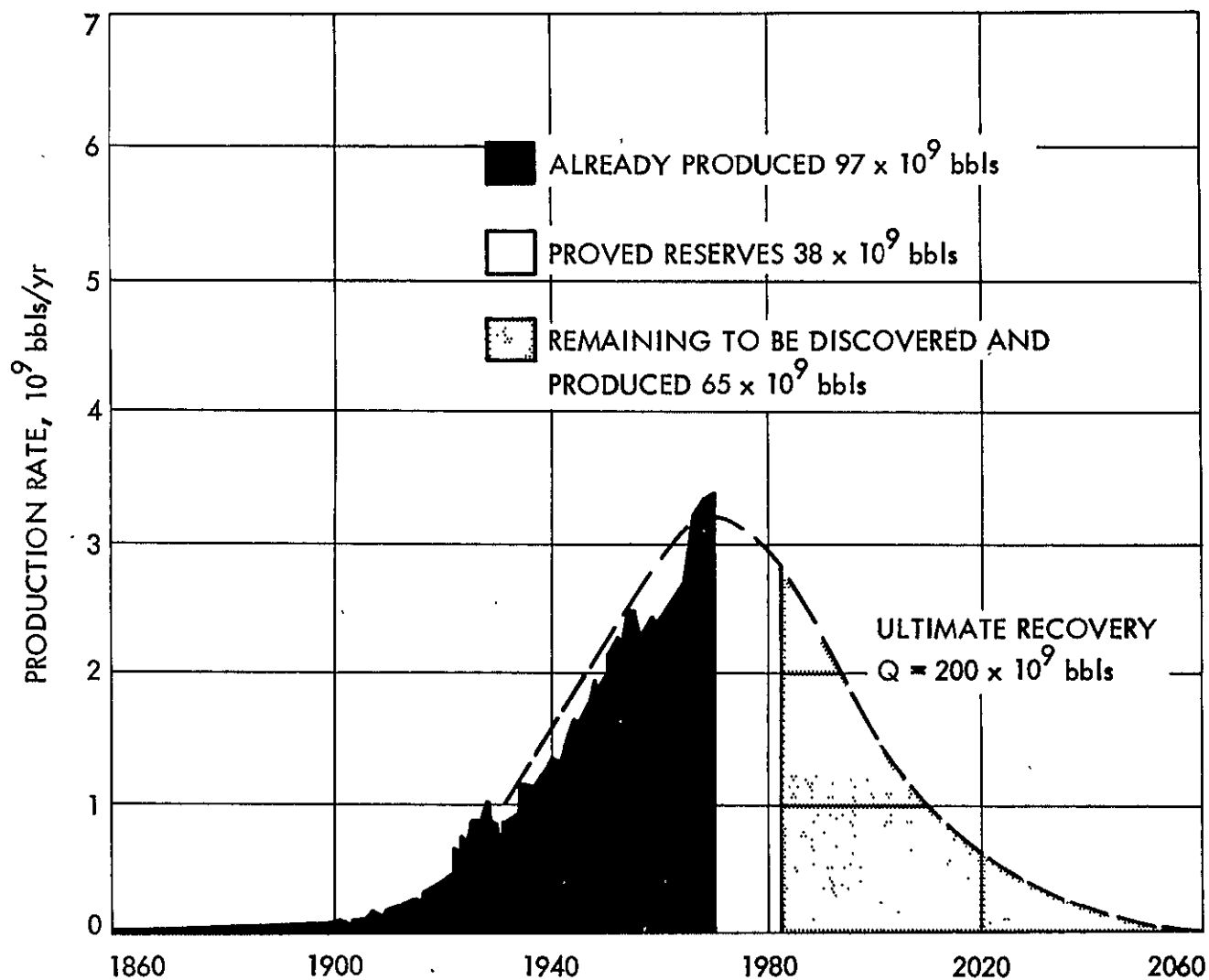


Figure 1-14. Depletion of Domestic Crude Oil Reserves

Source: David White, Technology Review, December 1972.

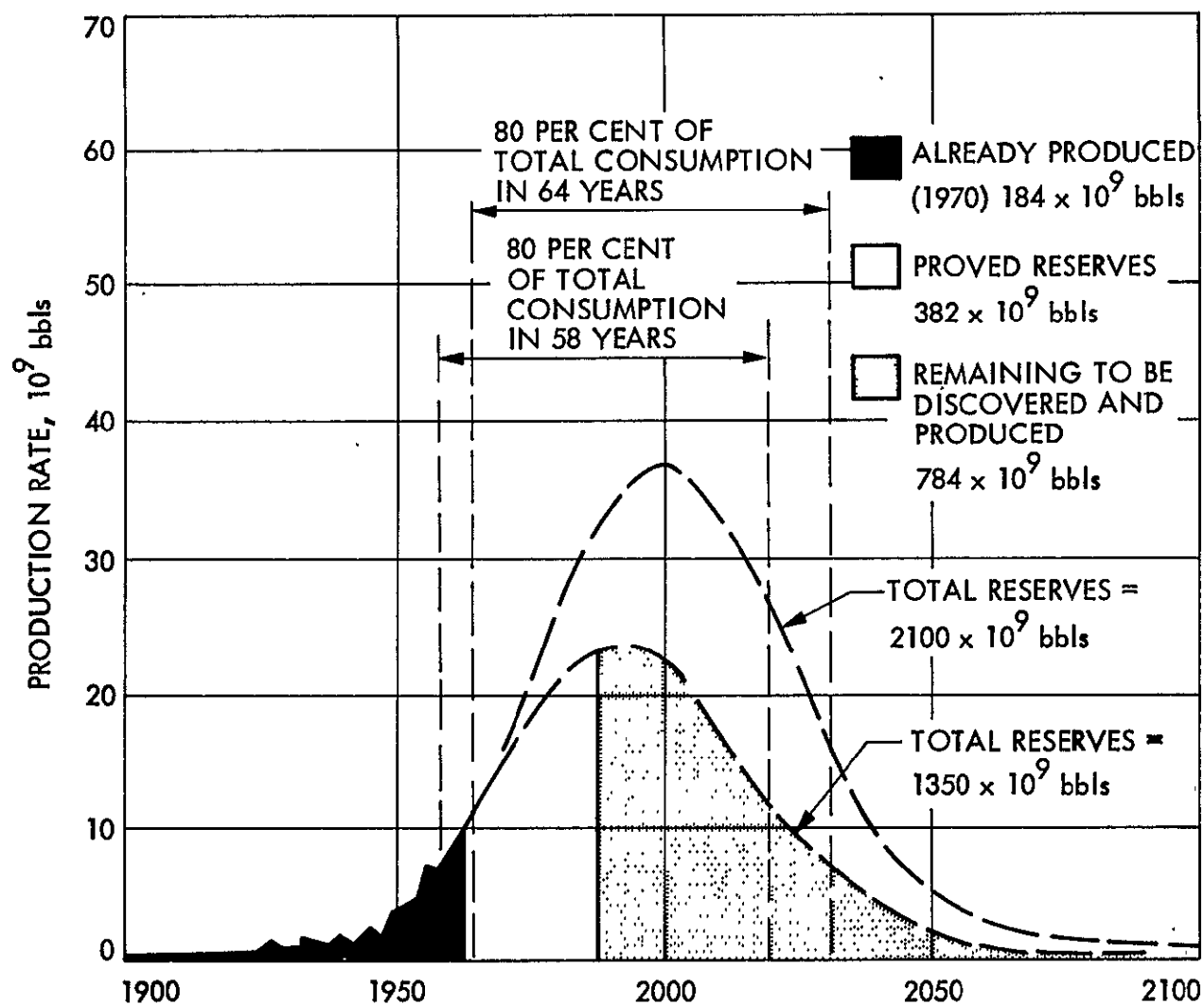
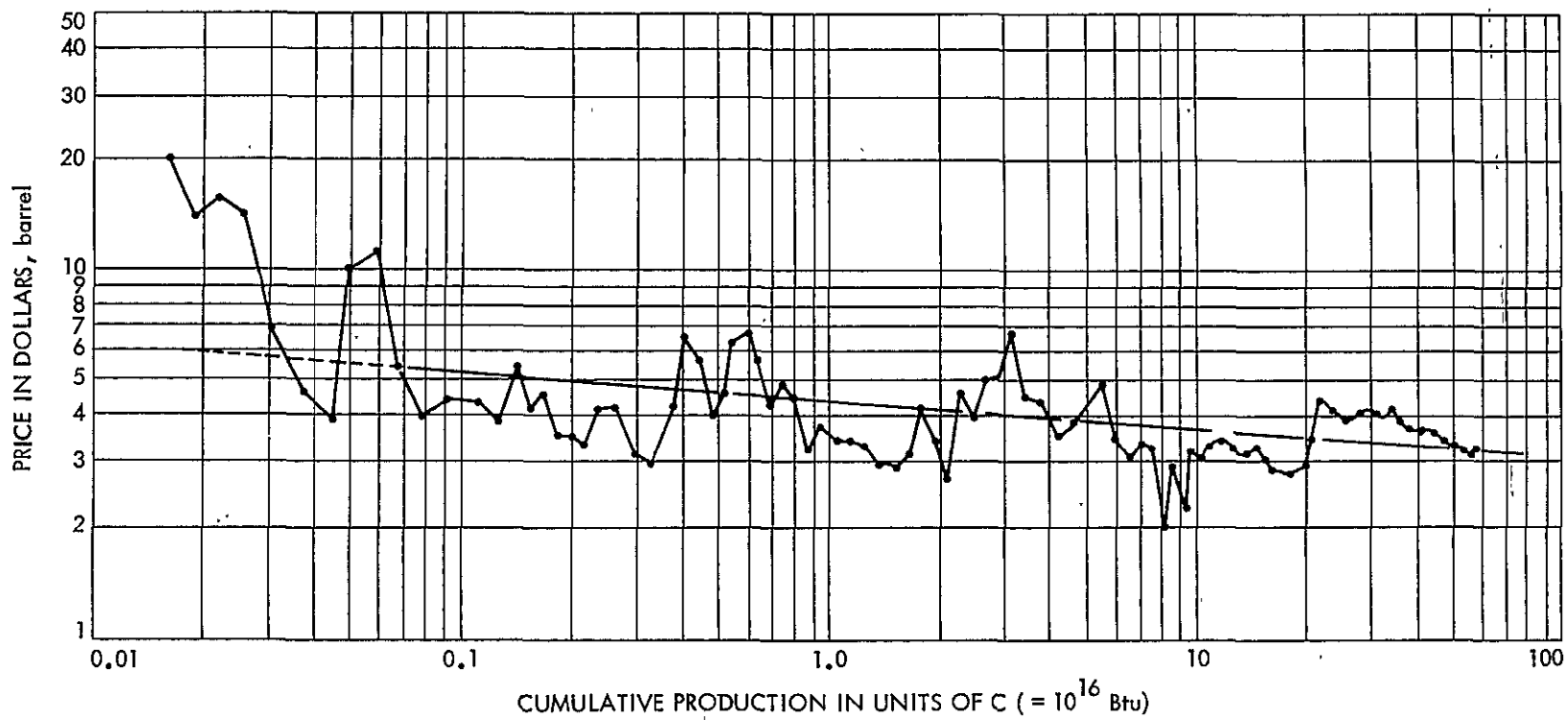


Figure 1-15. Depletion of World Crude Oil Reserves

Source: White, 1972.



Source: Fisher, 1974.

Figure 1-16. Cost of United States Crude Oil at the Well, 1935 to 1941

corresponds to a 5% decline in cost for every doubling of production. Yet as we approach depletion, the costs of oil production may be expected to rise as shown in Figure 1-17. The economic impact of the price rise might be quite large if life-styles and other factors limit the deployment of alternate technology.

Finally, social and environmental problems are confronting the energy picture, producing more uncertainty. The combination of our one option, R&D funding (nuclear fission), and our pricing policies which kept oil and natural gas low encouraging consumption, produced a difficult climate. When, for environmental and political reasons, nuclear power plants became embroiled in controversy, the result was increased pressure on our energy management resources. The average time from project start to nuclear power start-up takes almost 10 years (Figure 1-18). Environmental concerns which (rightfully) slowed the Alaskan pipeline and forced a slow power plant switch-over from coal to petroleum further heightened the dilemma.

In these ways we have an energy dilemma which is not strictly a depletion problem, but which includes questions of time frame, economics, and socio-environmental acceptability.

In this sense solar energy can play an important role in overcoming the supply/demand mismatch gap during the next 25 years. It has all the necessary characteristics of a viable option in the four senses just discussed. It is not depletable. For heating and cooling of buildings, it is a technology that is available and requires little R&D work. The social and environmental qualities of solar energy are quite favorable. No adverse environmental impacts are discernible and it has achieved widespread public favor. The economics of solar energy are nearly competitive with conventional heating and water heating sources. It is cheaper than electricity, but more expensive than (regulated) natural gas. (Table 1-24 summarizes the costs of the different fossil fuels and solar energy. Figure 1-19 is a graph of the relationship between these fuel prices for different efficiencies.)

The remaining problem with solar energy is the time scale. If solar energy is to play a significant role in solving the dilemma, it must achieve

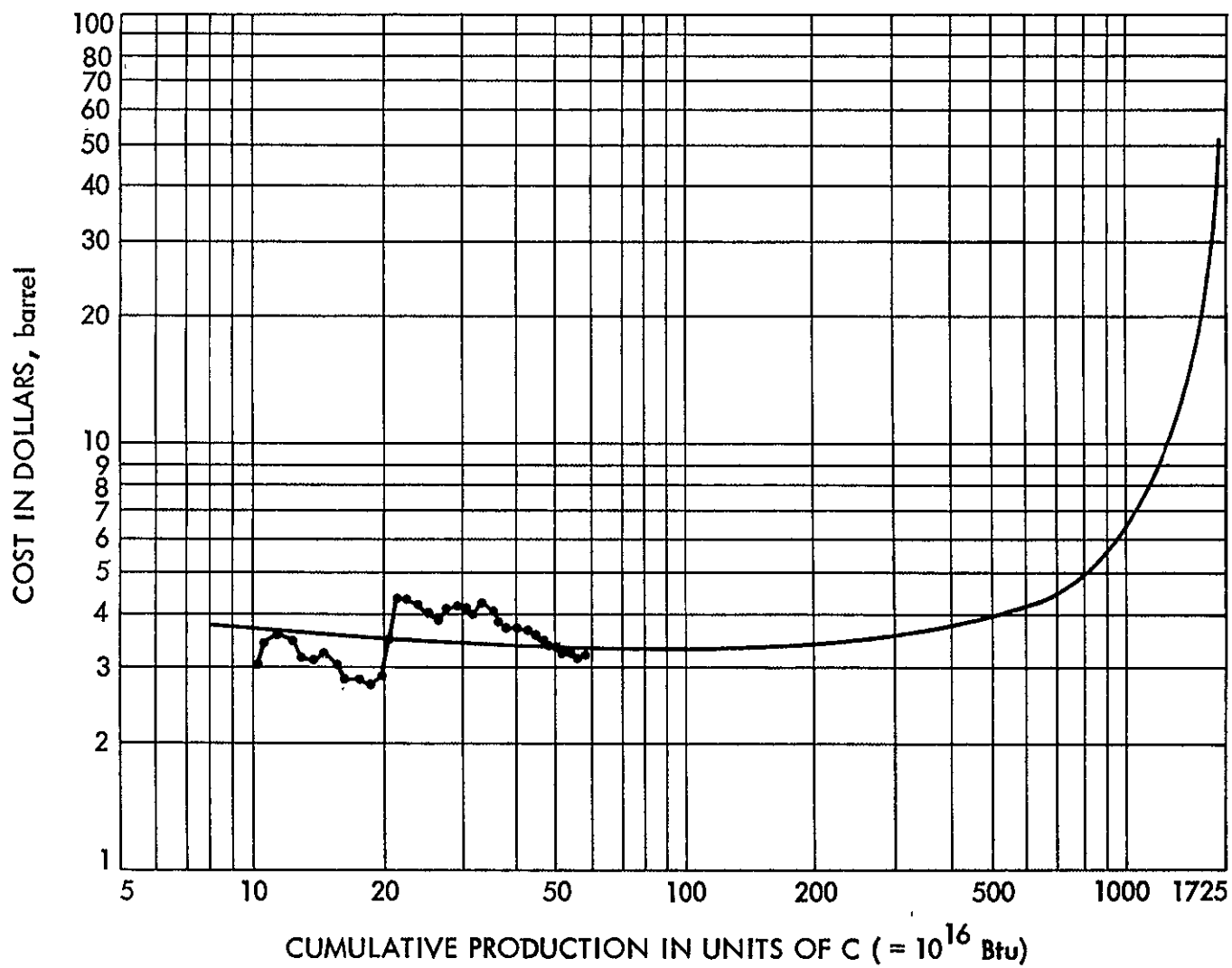


Figure 1-17. Crude Oil Cost Projected Toward Depletion
for a Total Resource Base of 17,250 Q

IT NOW REQUIRES ABOUT TEN YEARS TO PLAN AND CONSTRUCT SUCH A FACILITY FOR ELECTRICITY GENERATION. ABOUT HALF OF THIS TIME IS DEVOTED TO CONSTRUCTION.

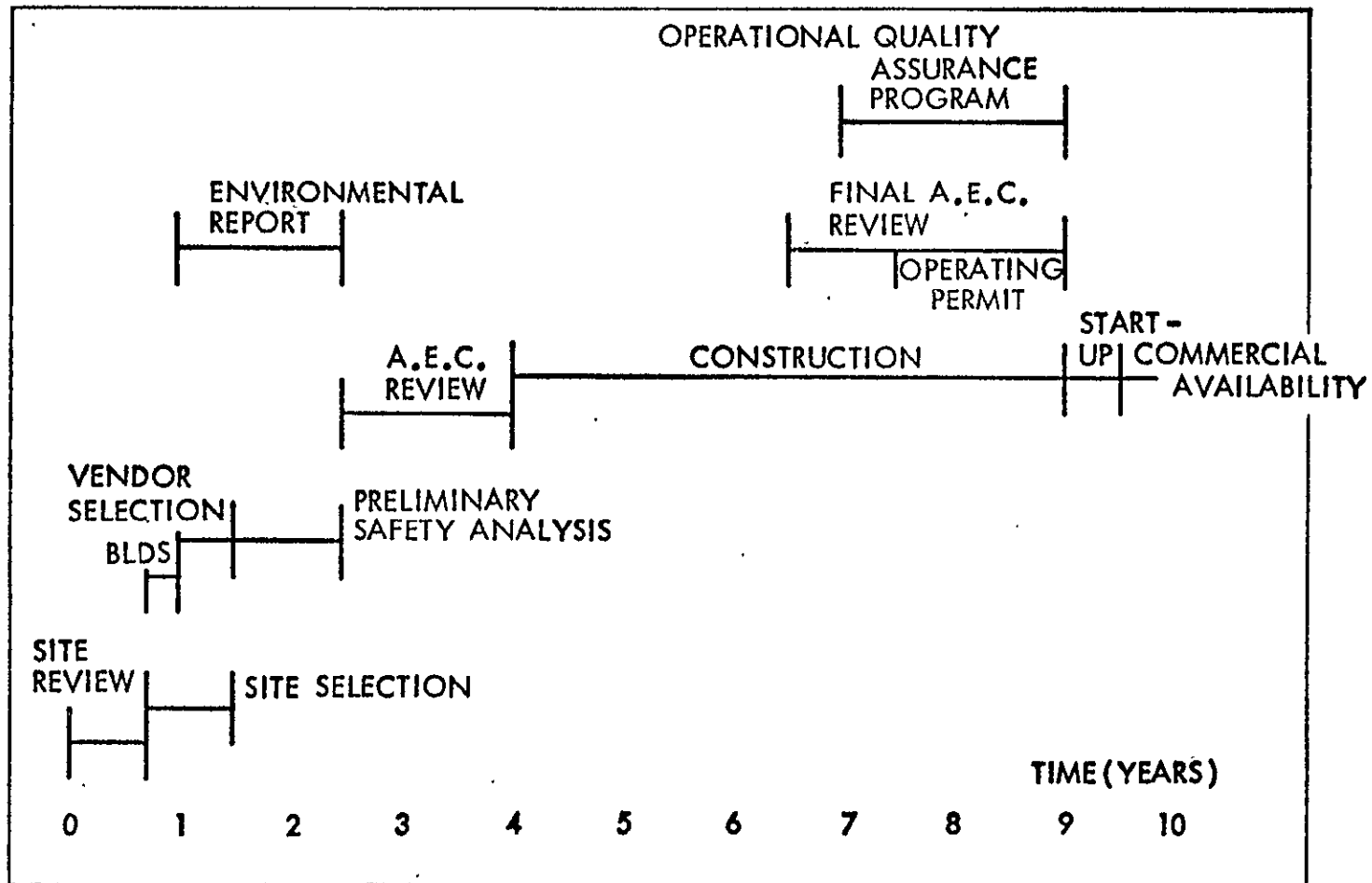


Figure 1-18. Planning Schedule for a Light-Water Reactor Plant

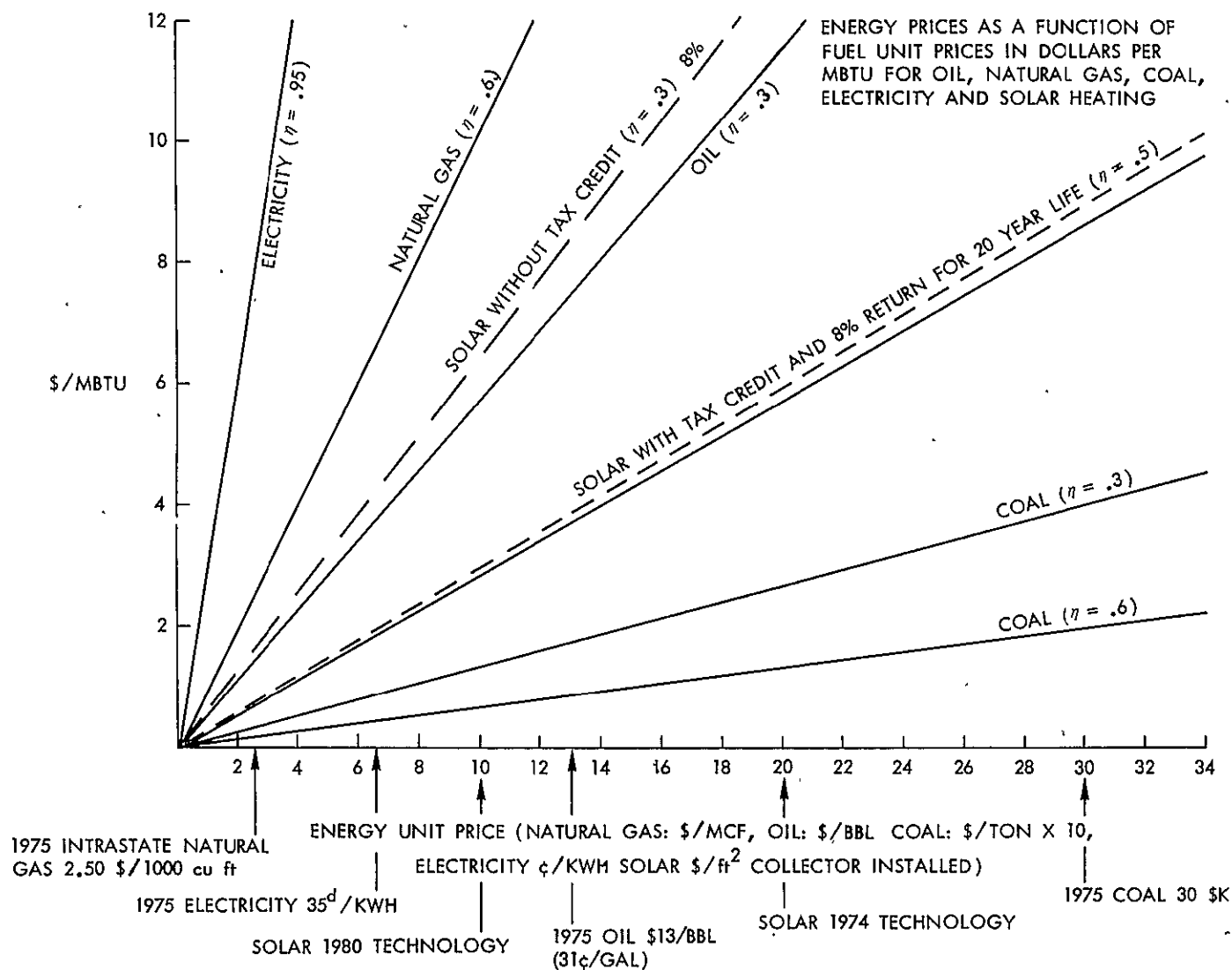


Figure 1-19. Fuel Price Comparison for Different Efficiencies and for Solar Energy

rapid and widespread use. However, until very recently, solar energy has been virtually ignored. The primary problem for solar energy (for heating and cooling of buildings) is rapid implementation.

REFERENCES

- 1-1. Grove, Noel. "Oil, The Dwindling Treasure." National Geographic, pp. 792-825, June 1974.
- 1-2. Rose, David J. "Energy Policy in the U.S." Scientific American, Vol. 230, No. 1, pp. 20-29, January 1974.
- 1-3. Simon, Herbert A. Administrative Behavior. New York: The Free Press, 1945.
- 1-4. Marcuse, Herbert. Eros and Civilization. New York: Vintage Books, 1962.
- 1-5. Henry, Jules. Culture Against Man. New York: Vintage Books, 1963.
- 1-6. Field, Stanford. "The U.S. Energy Puzzle." Paper presented to American Petroleum Institute, May 1973.
- 1-7. Moore, J. Cordell. "Some Distinguishing Features of U.S. Energy Policy," Address to 11th Session of the Energy Committee Organization of Economic Cooperation and Development, 1967.
- 1-8. Resources for the Future. U.S. Energy Policies: An Agenda for Research, A Staff Report. Baltimore: John Hopkins Press, 1968.
- 1-9. Stanford Research Institute. Patterns of Energy Consumption in the United States, January 1972.
- 1-10. Fisher, John C. Energy Crises in Perspective. London: John Wiley and Sons, 1974.
- 1-11. American Petroleum Institute. Annual Statistical Review. September 1974.
- 1-12. Hammond, Allen L., Metz, William D. and Maugh II, Thomas H. Energy and the Future. Washington, DC: American Association for the Advancement of Science, 1973.
- 1-13. Bezdek, Roger and Hannon, Bruce. "Energy Manpower and the Highway Trust Fund." Science, Vol. 185, pp. 669-674, 1974.
- 1-14. Brannon, Gerard M. Energy Taxes and Subsidies, Massachusetts: Ballinger Publishing Company, 1974.
- 1-15. Federal Highway Department. Federal Highway Report 94-75. Cited in Energy Today, Vol. III, No. 4, p. 30, October 1975.
- 1-16. Adelman, M. et al. "Energy Self-Sufficiency: An Economic Evaluation." Technology Review, May 1974.

- 1-17. Haveman, Robert H. The Economics of the Public Sector. New York: John Wiley and Sons, 1970.
- 1-18. Hirshberg, Alan S. "Implementation Centers: Interim Report." Unpublished report to the National Science Foundation, January 1976.
- 1-19. Nelson, Lorne W. "Reducing Fuel Consumption With Night Setback." ASHRAE Journal, pp. 16-24, August 1975.
- 1-20. Shell Oil Company. The National Energy Problem: Potential Energy Savings. Texas: October 1973.
- 1-21. Lees, Lester and Lo, Mingin Phillip. Time Factors in Slowing the Rate of Growth of Demand for Primary Energy in the U.S. Environmental Quality Report No. 7. Pasadena, California: California Institute of Technology, 1973.
- 1-22. Lees, Lester. "Why the Energy Crunch Came in the 70's." Cry California, pp. 16-26, 1972.
- 1-23. Cambel, A. B. et al. Energy R&D and National Programs: Findings and Conclusions. Washington, DC: U.S. Government Printing Office, 1966.
- 1-24. White, David C. "The Energy-Environment-Economic Triangle." Technology Review, Vol. 76, No. 2, pp. 10-19, December 1973.